Naval Fuels & Lubricants
Cross Functional Team
Research Report

50/50 JP5/ATJ5 SPECIFICATION AND FIT-FOR-PURPOSE TEST RESULTS

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LIST OF ACRONYMS/ABBREVIATIONS

American Society for Testing and Materials........ASTM

Alcohol to Jet Procured to Navy Specification Requirements ATJ-5

Defense Logistics Agency........DLA

Fit for Purpose........FFP

Hydroprocessed Renewable Jet Procured to Navy Specification Requirements........HRJ-5

Hydroprocessed Esters and Fatty Acids ....HEFA

Naval Air Systems Command ....NAVAIR

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Naval Middle Distillate Fuel, MIL-DTL 5624V........JP-5

Original Equipment Manufacturer ....OEM

Subject Matter Expert........SME

EXECUTIVE SUMMARY

In October 2009, Secretary of the Navy Ray Mabus directed the Navy to decrease its reliance on fossil fuels. The Secretary set a goal of operating with at least 50% of energy consumption coming from alternative sources by 2020, and demonstrating a Great Green Fleet in 2016. The use of petroleum/alternative sourced aviation fuel blends is a critical component to achieving these goals.

The approach of the Navy's alternative fuels qualification program is to ensure that proposed fuels perform similar to or better than equivalent petroleum fuels. The qualification testing conducted in accordance with Navy Standard Work Package 44FL-006, Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/ Fuel Sources[1] includes specification, fit-for-purpose, component testing, engine testing, and aircraft flight testing with decision points built in after each stage is completed. In general, the testing program progresses from low risk, low cost, low fuel consumption and least complex testing to the greatest of each of these categories.

This test report summarizes specification and fit-for-purpose (FFP) test results of a 50/50 blend of petroleum JP-5 and two alternative fuel blend stocks produced via the alcohol-to-jet synthetic paraffinic kerosene (ATJ-SPK) process (herein referred to as 50/50 JP5/ATJ5). ATJ-SPK was made by converting a biomass to an alcohol intermediary to a hydrocarbon that meets the military specification. The end product of the ATJ SPK process is very similar in chemistry to previously qualified aviation alternative fuel blend stocks, such as Hydroprocessed Esters and Fatty Acids (HEFA) and Fischer Tropsch (FT).

Two distinct batches of ATJ fuels were evaluated. These two batches were produced from two different types of butanol intermediaries but showed overall similar chemistry and physical properties. One of the 50/50 JP5/ATJ5 blends passed all FFP requirements set forth by in the Navy Standard Work Package 44FL-006[1]. The second 50/50 JP5/ATJ5 blend had a derived cetane number outside the range of petroleum JP-5. Cetane only affects diesel engines and mitigations for low cetane fuels in diesel engine applications are being considered. Viscosity at -20°C of the blends met the JP-5 specification; however these values fall near the upper end of the normal range operating experience. Additional investigation is being done to assess any potential risk of operating with viscosity in this regime. When both ATJ fuels are blended with petroleum JP-5, the properties of the two blends are very similar to one another. These test results support the continued qualification of 50/50 JP5/ATJ5 for use by the U.S. Navy and provide documentation to support the approval of all butanol based-ATJ blends under one qualification process.

50/50 JP5/ATJ5 SPECIFICATION AND FIT-FOR-PURPOSE TEST RESULTS

1.0 BACKGROUND

In October 2009, Secretary of the Navy Ray Mabus directed the Navy to decrease its reliance on fossil fuels. The Secretary set a goal of operating with at least 50% of energy consumption coming from alternative sources by 2020. He also set forth the goal of demonstrating a Great Green Fleet, operating on 50% alternative fuel sources, by 2012 and deploying by 2016. The use of alternative/ petroleum sourced aviation fuel blends is a critical component to achieving these goals. The alternative sourced fuels will come from non-food sources and must be compatible with all existing hardware without compromising performance, handling or safety. The increased use of alternative sources to produce Naval tactical fuels will increase the Navy's energy independence while improving national security, decreasing environmental impact and strengthening the national economy. The objective of this test program is to ensure that all proposed alternative fuels perform equally or better than existing petroleum sourced fuels.

2.0 APPROACH

The approach of the Navy's alternative fuels qualification program is to ensure that proposed fuels perform similar to or better than equivalent petroleum fuels. The qualification testing conducted in accordance with Navy Standard Work Package 44FL-006, Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/ Fuel Sources[1], includes specification, fit-for-purpose, component testing, engine testing, and aircraft flight testing with decision points built in after each stage is completed. In general, the testing program progresses from low risk, low cost, low fuel consumption and least complex testing to the greatest of each of these categories. This report discusses the results of specification and fit-for-purpose testing. Follow on reports will be issued as component testing, engine testing, and full scale demonstrations are completed.

2.1 Fuels

The alternative sourced fuel currently under-going qualification testing is a 50/50 blend of petroleum JP-5 and an alternative fuel blend stock produced via the alcohol-to-jet synthetic paraffinic kerosene (ATJ-SPK) process (herein referred to as 50/50 JP5/ATJ5). ATJ is a process that chemically converts alcohols, such as ethanol or butanol, to hydrocarbons found in jet fuels. Alcohols can be produced from a variety of feedstocks including sugar, corn, grasses, or other biomasses. Different ATJ processes can use a variety of starting alcohols and produce synthetic paraffins (SPKs), synthetic aromatics (SKAs) or mixtures of both. Currently, the Navy is working to qualify ATJ processes made from butanol starting materials and which produce SPK's. All other ATJ processes are not evaluated in this paper and will require separate qualification and approval before acceptance into the JP-5 specification. ATJ-SPK fuel blend stocks are made from direct dehydration of an alcohol to produce an alkene (olefins), a short carbon chain hydrocarbon. These alkenes then go through an oligimerization or "building up"

process in which smaller alkenes are joined with each other to produce larger alkenes. The alkenes are then hydrogenated into alkanes (paraffins) to stop further reaction and separated to produce a mixture of hydrocarbons with boiling points in the range of typical jet fuel. To represent this class of renewable fuel, DLA Energy contracted on behalf of the Navy to procure ATJ-5 that could meet the JP-5 specification when blended 50/50 v/v with petroleum JP-5. This fuel was similar to petroleum fuels and Hydroprocessed Esters and Fatty Acids (HEFA)[a] fuels, also called Hydroprocessed Renewable Jet fuels (HRJ-5), which also had a broad range of different normal and iso paraffins.

Figure 1. Alcohol to Jet Conversion Process

There were two different types of butanol used to produce the ATJ-5 tested in this report. The first type of ATJ-5 was derived from n-butanol and will herein be referred to as Cobalt ATJ-5. The second type of ATJ-5 was derived from isobutanol and will herein be referred to as Gevo ATJ-5. The main differences between the two ATJ-5 sources were the increased methyl branching in the hydrocarbon end products of the isobutanol derived fuel. The isobutanol derived ATJ can have up to nine methyl branches whereas the n-butanol derived ATJ has around three methyl branches. The differences in branching lead to slight differences in chemical and physical properties of the fuel. These differences, while minor, are discussed later in this report.

Two distinct batches of ATJ-5 were evaluated for this report. Cobalt ATJ-5 was defined as the 30 gallon batch received on June 28, 2012. Gevo ATJ-5 was the 800 gallon procurement received on July 29, 2013. Cobalt ATJ-5 was blended 50%/50% (by volume) with JP-5 and is herein referred to as 50/50 JP5/Cobalt ATJ5. Gevo ATJ-5 was also blended 50%/50% (by volume) with JP-5 and is herein referred to as 50/50 JP5/Gevo ATJ5.

2.2 Specification Testing

The ATJ-5 procurement specification describes requirements neat ATJ-5 must meet at the time of delivery to the Navy. The procurement specification for neat ATJ-5 is provided in Appendix A.

Naval aviation turbine fuel (petroleum), JP-5, is governed by MIL-DTL-5624. 50/50 JP5/ATJ5 must meet all requirements of MIL-DTL-5624 in order to continue qualification. The most recent version of this military specification can be found at http://quicksearch.dla.mil/.

[a] The commercial aviation industry has elected to use the term HEFA – Hydroprocessed esters and Fatty Acids – because it better defines the actual process and materials being qualified for aviation use. The US Air Force, which embarked on qualification work prior to the commercial sector, chose at that time to use the terminology HRJ – Hydroprocessed Renewable Jet. In this paper the terms HRJ and HEFA are used interchangeably.

2.3 Fit-for-Purpose Testing

Fit-for-Purpose (FFP) properties are chemical and physical properties of a fuel that are not typically measured for petroleum derived fuels because they are inherently acceptable. These properties impact the performance, material compatibility, handling, and safety of the fuel and therefore must be evaluated for any new non-petroleum source proposed to produce JP-5. The FFP properties were chosen through consultations with original equipment manufacturers (OEMs) and Navy subject matter experts (SMEs) as those that could reveal effects to their relevant equipment. The purpose of testing FFP properties is to ensure that there are no unintentional consequences in properties not governed by the specification due to changing the source to produce the fuel. The FFP properties are split into two levels. Level I properties can be tested using small amounts of fuel (typically 5 gallons) while Level II tests generally require larger fuel volumes (approximately 200 gallons), are more complex, and typically require longer schedule lead times. This report provides Level I and some Level II results. Additional information about the FFP selection criteria can be found in Reference 1. Additional information about the parameters and limits for FFP Level I and Level II tests can be found in Appendix B and Appendix C respectively.

3.0 RESULTS & DISCUSSION

3.1 Alcohol to Jet (ATJ) Procurement Specification Test Results

The neat alcohol-to-jet fuel must meet ATJ-5 procurement specification requirements before consideration for qualification. These requirements are found in Appendix A. Cobalt ATJ-5 and Gevo ATJ-5 procurement specification data is displayed in Table 1. Cobalt ATJ-5 met all the procurement requirements except antioxidant concentration. Antioxidant additive was intentionally not added to the Cobalt ATJ-5 due to the small sample size. Any possible future bulk procurements of Cobalt ATJ-5 will be additized appropriately. The slightly high, but within specification, silicon concentration in Cobalt ATJ-5 was likely due to external contamination and not inherent to the production of the ATJ-5. The Gevo ATJ-5 did not meet distillation residue requirements. This is believed to be due to the small sample being processed at a pilot plant and is not expected to fail at larger procurement quantities. None of these deviations were considered to be significant to adversely impact planned specification and fit for purpose testing and will be within specification as larger quantities are procured.

Table 1. ATJ-5 Procurement Specification Data for Neat Cobalt ATJ-5 and Neat Gevo ATJ-5

Test	Parameter	Method	Units	Minimum	Maximum	Cobalt ATJ-5	Gevo ATJ-5
Flash Point		D93	°C	60		67	60
Density at 15°C		D4052	kg/L	0.760	0.845	0.777	0.774
Total Water		D6304	ppm		75	10	12
Particulate Contamination		D5452	mg/L		1.0	0.0	0.0
Filtration Time		MIL-DTL-5624U	minutes		15	7	6
Viscosity at -20°C		D445	mm^2/s		8.5	8.3	8.4
Derived Cetane Number		D6890	-----	Report		49	17
Distillation	Initial Point	D86	°C	Report		187	179
	10% Recovered	D86	°C		205	202	188
	50% Recovered	D86	°C	Report		219	206
	90% Recovered	D86	°C	Report		252	249
	End Point	D86	°C		300	256	273
	Residue	D86	Volume %		1.5	1.5	**1.7**
	Loss	D86	Volume %		1.5	0.1	0.4
	T90-T10		°C	25		50	60
Copper Strip Corrosion at 100°C		D130	-----		1	1a	1a
Freezing Point		D5972	°C		-46	-82	<-82
Hydrogen Content		D7171	Mass %	13.4		14.9	15.0
Heating Value		D4809	MJ/kg	42.8		44.1	44.3
Acid Number		D3242	mgKOH/g		0.015	0.002	0.003
MSEP		D3948	-----	80		98	99
JFTOT	Tube Deposit Rating	D3241	-----		<3	1	<1
	ΔP	D3241	mm Hg		25	0	0
Additives	Antioxidant A		ppm			0	0
	Antioxidant B		ppm			0	16.6
	Antioxidant C		ppm			0	0
	Total Antioxidant		ppm	17.2	24.0	**Not Additized**	16.6
Sulfur, Total	UV Fluorescence	D5453	ppm		15	3	1
Nitrogen Content		D4629	ppm		10	2	1
Hydrocarbon Composition	Paraffins	D2425	Mass %		Report	98	99
	Cyclo Paraffins	D2425	Mass %		30	0	0
	Total Aromatics	D2425	Mass %		0.5	0	0
Metals	Ca	D7111	ppm			< 0.1	< 0.1
	Cu	D7111	ppm			< 0.1	< 0.1
	Fe	D7111	ppm			< 0.1	< 0.1
	Mg	D7111	ppm			< 0.1	< 0.1
	Mn	D7111	ppm			< 0.1	< 0.1
	Ni	D7111	ppm			< 0.1	< 0.1
	P	D7111	ppm			< 0.1	< 0.1
	Pb	D7111	ppm			< 0.1	< 0.1
	V	D7111	ppm			< 0.1	< 0.1
	Zn	D7111	ppm			< 0.1	< 0.1
	Total Metals	D7111	ppm		0.5	< 0.1	< 0.1
Alkali Metals & Metalloids	B	D7111	ppm			0.1	0.1
	Na	D7111	ppm			< 0.1	< 0.1
	K	D7111	ppm			< 0.1	0.1
	Si	D7111	ppm			0.7	< 0.1
	Li	D7111	ppm			< 0.1	< 0.1
	Total	D7111	ppm		1.0	0.8	0.2

** Values highlighted in red denote properties that do not meet procurement requirements*

3.2 MIL-DTL-5624V JP-5 Specification Test Results

50/50 JP5/ATJ5 fuels were evaluated for specification properties according to MIL-DTL-5624V. Specification properties of the base petroleum JP-5 and the unblended ATJ-5 fuels were also tested for comparison purposes only. Specification results for the base petroleum fuel, Cobalt and Gevo ATJ-5 fuels and blends are summarized in Tables 2 and 3 respectively. As was the case with HEFA, a paraffinic jet fuel previously qualified, the density of neat ATJ-5 was below specification limits. The density of ATJ-5 improved upon blending with petroleum JP-5, and all blends will be required to meet minimum density requirements in MIL-DTL-5624. Neat Gevo ATJ-5 exceeded the existent gum content, but blending with JP-5 brought this property within specification. Existent gums can be eliminated by further processing during the production of the fuel. Specification limits will ensure that neat ATJ-5 meets the gum content requirement before full-scale procurement.

The 50/50 JP5/ATJ5 fuel blends and neat petroleum JP-5 met the specification requirements with the exception of distillation residue for the 50/50 JP5/Gevo ATJ5 blend. As described in section 3.1, Gevo ATJ-5 exceeded the limits for distillation residue. This property will be controlled through the specification to be no worse than current petroleum fuels. The neat Cobalt ATJ-5 and Gevo ATJ-5 fuels did not meet all the chemical and physical requirements of MIL-DTL-5624V, and are not considered a fit for purpose finished fuel for aviation applications. The data is presented for information purposes only.

Table 2. Fuel Specification Test Results for Cobalt ATJ-5, 50/50 JP5/Cobalt ATJ5, and Petroleum JP-5

Test	Method	Minimum	Maximum	Cobalt ATJ-5	50/50 JP-5/Cobalt ATJ-5 Blend	JP-5
Color, Saybolt	D156	Report		>30	22	16
Total Acid Number (mgKOH/g)	D3242		0.015	0.002	0.002	0.003
Aromatics (Volume %)	D1319	8	25	**Not Detected**	9.9	19
Sulfur, Mercaptan (Mass %)	D3227		0.002	0.001	0.001	0.002
Sulfur, Total						
XRF (Mass %), or	D4294		0.20	0.00	0.07	0.13
UV Fluorescence (ppm)	D5453		2000	3	N/A	N/A
Distillation	D86					
Initial (°C)		Report		187	182	183
10% Recovered (°C)			205	202	197	194
20% Recovered (°C)		Report		207	203	199
50% Recovered (°C)		Report		219	215	212
90% Recovered (°C)		Report		252	246	236
End Point (°C)			300	256	255	254
Residue (Volume %)			1.5	1.5	1.5	1.1
Loss (Volume %)			1.5	0.1	0.2	0.3
Flash Point (°C)	D93	60		67	64	62
Density at 15°C (g/mL)	D4052	0.788	0.845	**0.777**	0.796	0.814
Freezing Point (°C)	D5972		-46	-82	-58	-50
Viscosity at -20°C (mm^2/s)	D445		8.5	8.3	6.4	5.3
Net Heat of Combustion (MJ/kg)	D4809	42.6		44.1	43.6	42.7
Derived Cetane Number	D6890	Report		49	46	44
Hydrogen Content (Mass %)	D7171	13.4		14.9	14.2	13.6
Smoke Point (mm)	D1322	19		43	29	22
Copper Strip Corrosion at 100°C	D130		1	1a	1a	1a
Thermal Stability	D3241					
Pressure Drop (mm Hg)			25	0	0	0
Heater Tube Deposit			<3	1	<1	<1
Existent Gum (mg/100mL)	D381		7	2	2	0
Particulate Matter (mg/L)	D5452		1.0	0.0	0.2	0.2
Filtration Time (minutes)	MIL-DTL-5624V		15	7	7	5
Micro Separometer Rating	D3948	70		98	80	84
Fuel System Icing Inhibitor (Volume %)	D5006	0.10	0.15	0.00[b]	0.05[c]	0.08[c]

[b] FSII was intentionally not added to this product
[c] Meets use limit of 0.03 defined by NATOPS 00-80T-109

**Values highlighted in blue denote blend limiting properties*

Table 3. Fuel Specification Test Results for Gevo ATJ-5, 50/50 JP5/Gevo ATJ5, and Petroleum JP-5

Test	Method	Minimum	Maximum	Gevo ATJ-5	50/50 JP-5/ Gevo ATJ5 Blend	JP-5
Color, Saybolt	D156	Report		>30	20	17
Total Acid Number (mgKOH/g)	D3242		0.015	0.003	0.001	0.004
Aromatics (Volume %)	D1319	8	25	Not Detected	11	18
Sulfur, Mercaptan (Mass %)	D3227		0.002	0.000	0.001	0.001
Sulfur, Total						
XRF (Mass %), or	D4294		0.20	N/A	0.05	0.13
UV Fluorescence (ppm)	D5453		2000	<1	N/A	N/A
Distillation	D86					
Initial (°C)		Report		179	177	179
10% Recovered (°C)			205	188	189	191
20% Recovered (°C)		Report		193	194	196
50% Recovered (°C)		Report		206	207	208
90% Recovered (°C)		Report		249	242	233
End Point (°C)			300	273	267	250
Residue (Volume %)			1.5	1.7	1.6	1.4
Loss (Volume %)			1.5	0.4	0.2	0.1
Flash Point (°C)	D93	60		60	62	64
Density at 15°C (g/mL)	D4052	0.788	0.845	0.774	0.794	0.811
Freezing Point (°C)	D5972		-46	<-82	-58	-57
Viscosity at -20°C (mm^2/s)	D445		8.5	8.4	6.1	5.0
Net Heat of Combustion (MJ/kg)	D4809	42.6		44.3	43.5	43.0
Derived Cetane Number	D6890	Report		17	37	43
Hydrogen Content (Mass %)	D7171	13.4		14.9	14.4	13.6
Smoke Point (mm)	D1322	19		33	26	21
Copper Strip Corrosion at 100°C	D130		1	1a	1a	1a
Thermal Stability	D3241					
Pressure Drop (mm Hg)			25	0	0.1	0
Heater Tube Deposit			<3	<1	1	1
Existent Gum (mg/100mL)	D381		7	9	5	2
Particulate Matter (mg/L)	D5452		1.0	0.0	0.2	0.2
Filtration Time (minutes)	MIL-DTL-5624V		15	6	5	5
Micro Separometer Rating	D3948	70		99	81	80
Fuel System Icing Inhibitor (Volume %)	D5006	0.10	0.15	0.00[d]	0.07[e]	0.13

[d] FSII was intentionally not added to this product

[e] Meets use limit of 0.03 defined by NATOPS 00-80T-109

**Values highlighted in red denote fuel properties that do not meet specification requirements*

*** Values highlighted in blue denote blend limiting properties*

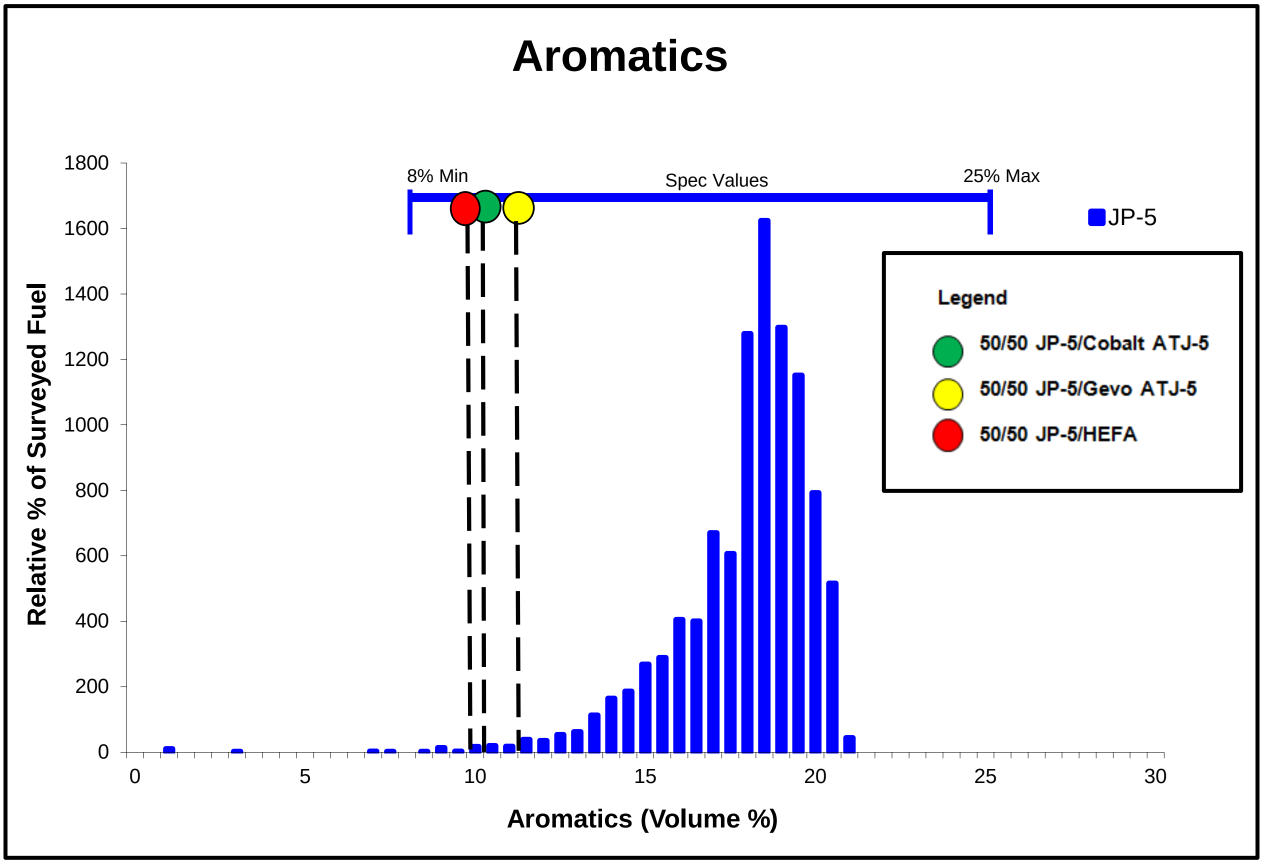

Figure 2. Aromatics content of 50/50 JP5/Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 compared to 50/50 JP5/HEFA[2] and Historical JP-5 data

The aromatic content of the Cobalt 50/50 blend and the Gevo 50/50 blend both met the FFP acceptance criteria of 8%-25% by volume. Aromatic content can affect the performance of some non-metallic materials such as O-rings and gaskets. Aromatic content is directly related to volumetric heat of combustion, density, and autoignition temperature. Neat ATJ-5 contains very little aromatics but upon blending, the aromatics present in JP-5 allow the blend to pass FFP limits. Figure 2 shows the aromatic content of the ATJ-5 and HEFA blends along with aromatic content of historic JP-5 fuels sampled from 1990-2012. Although the blends lie near the minimum aromatics limit, extensive testing with HEFA blends has verified the specification aromatics minimum limit[2,3,4]. Blending ATJ-5 50/50 with petroleum JP-5 increases the aromatic content and passes the specification acceptance criteria.

As a reference, 50/50 JP5/HEFA data is also shown for comparison in select specification properties since it has successfully completed qualification and was incorporated into the JP-5 specification. Some properties of JP5/HEFA can serve as a useful reference to show an acceptable fuel which is near the limits of the specification or FFP criteria. For example, Figure 2 shows that the JP5/HEFA blend was near the minimum acceptance level for aromatic content, but still within specification limits. The JP5/ATJ blends had a similar aromatic content compared to the JP5/HEFA and is expected to perform no worse than the previously qualified JP5/HEFA alternative fuel blend.

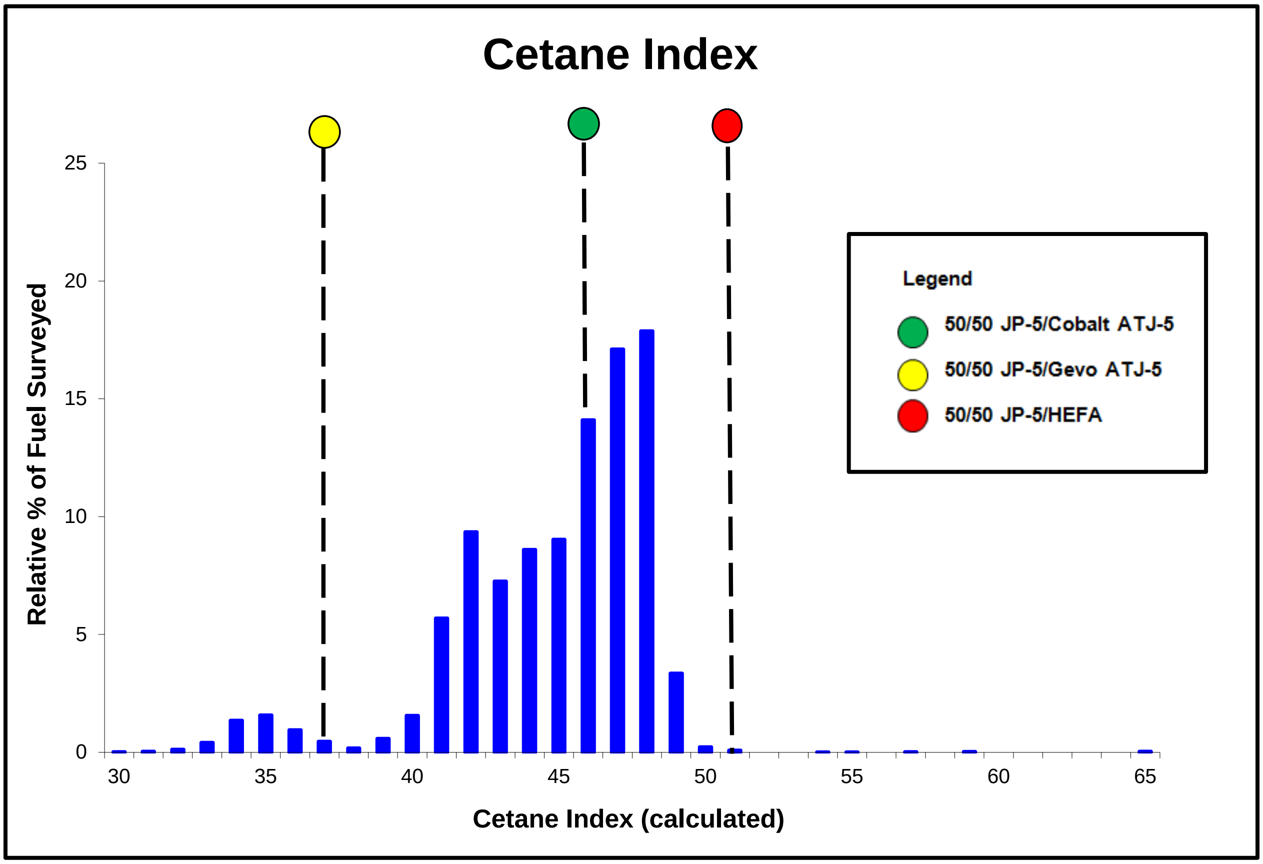

Figure 3. Cetane Number of 50/50 JP5/Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 compared to 50/50 JP5/HEFA[2] and Historical JP-5 Cetane Index data

Cetane is a property important to the cold starting of diesel engines. JP-5 is used as an alternative ship propulsion fuel. It is also the primary fuel for use in emergency diesel generators aboard aircraft carriers. Therefore, any alternative sourced fuel must not impact diesel engine performance. Although cetane index is a "report only" value in the JP-5 specification, a fit for purpose limit of 42 derived cetane number was established for all blends of alternative fuels[1]. Derived cetane number is an empirical measurement whereas cetane index estimated based upon density and distillation. Derived cetane is the preferred measurement because this value is based on an accurate test method that measures a fuel's ignition delay via the ignition quality tester (IQT). Historically, only cetane index has been collected on JP-5 because cetane index is a calculated number based on density and distillation range. For purposes of this report, derived cetane number of the alternative fuel blends are being compared directly to cetane index of JP-5 since this is the only historical data available.

Blends of 50/50 JP5/Cobalt ATJ5 fell within typical range for petroleum JP-5 cetane. Blending neat JP-5 with Gevo ATJ-5 reduced the cetane number of the blended fuel compared to the neat JP-5. This is due to the fact that the cetane value for neat Gevo ATJ-5 was significantly lower than typical JP-5. Mitigations for diesel engine qualification will be discussed in the recommendations section.

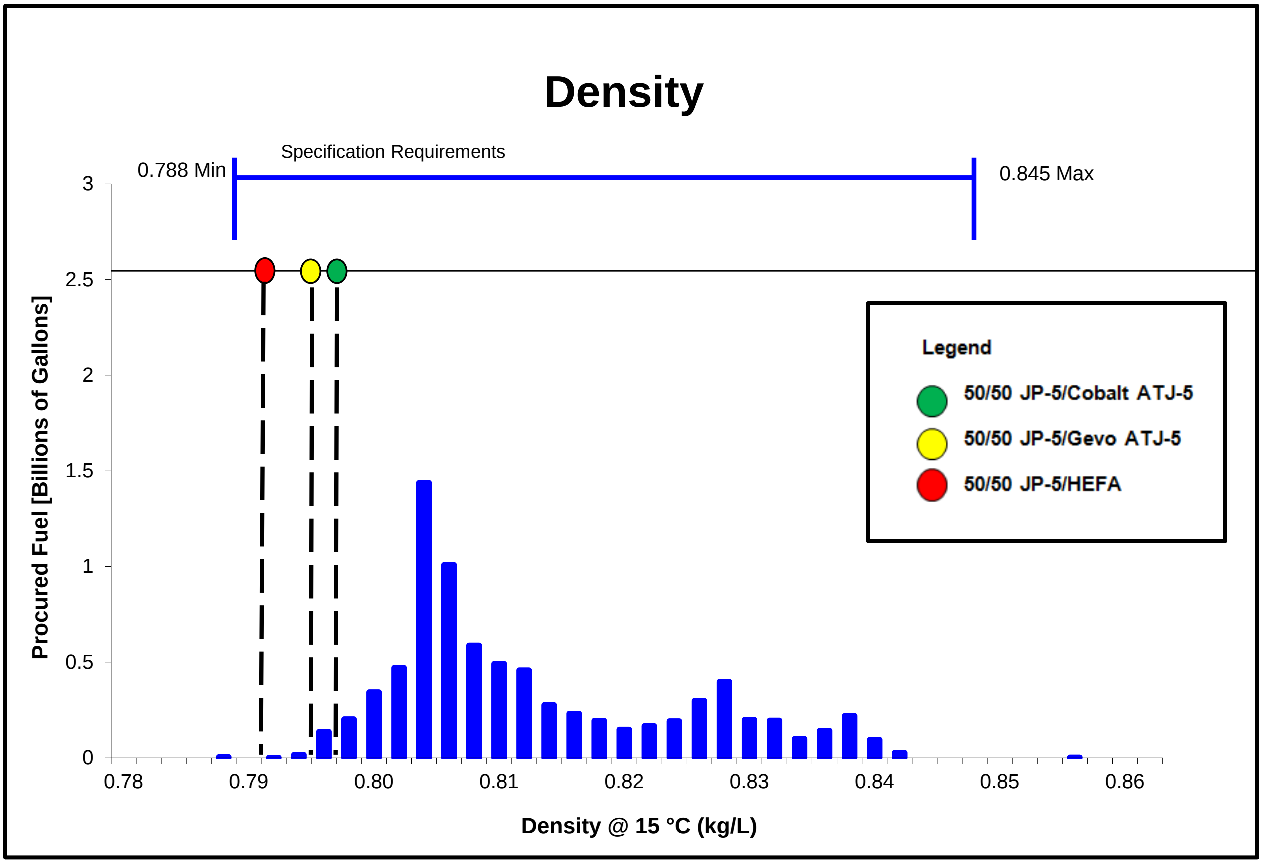

Figure 4. Density of 50/50 JP5/Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 compared to 50/50 JP5/HEFA[2] and Historical JP-5 data

Figure 4 shows the density distribution of all JP-5 procured by the US Navy between 1990-2012. As was the case with aromatics, the density of the Cobalt and Gevo ATJ-5 blends meet the specification criteria range of 0.788-0.845 kg/L, but fell near the historical minimum density of typical petroleum JP-5. The 50/50 JP5/Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 are both shown in comparison to the 50/50 JP5/HEFA blend. The density values for the ATJ-5 blends were within the range of 50/50 JP5/HEFA. Extensive aviation flight testing and qualification of HEFA blends with similar densities have shown no adverse effects[5, 6, 7, 8, 9].

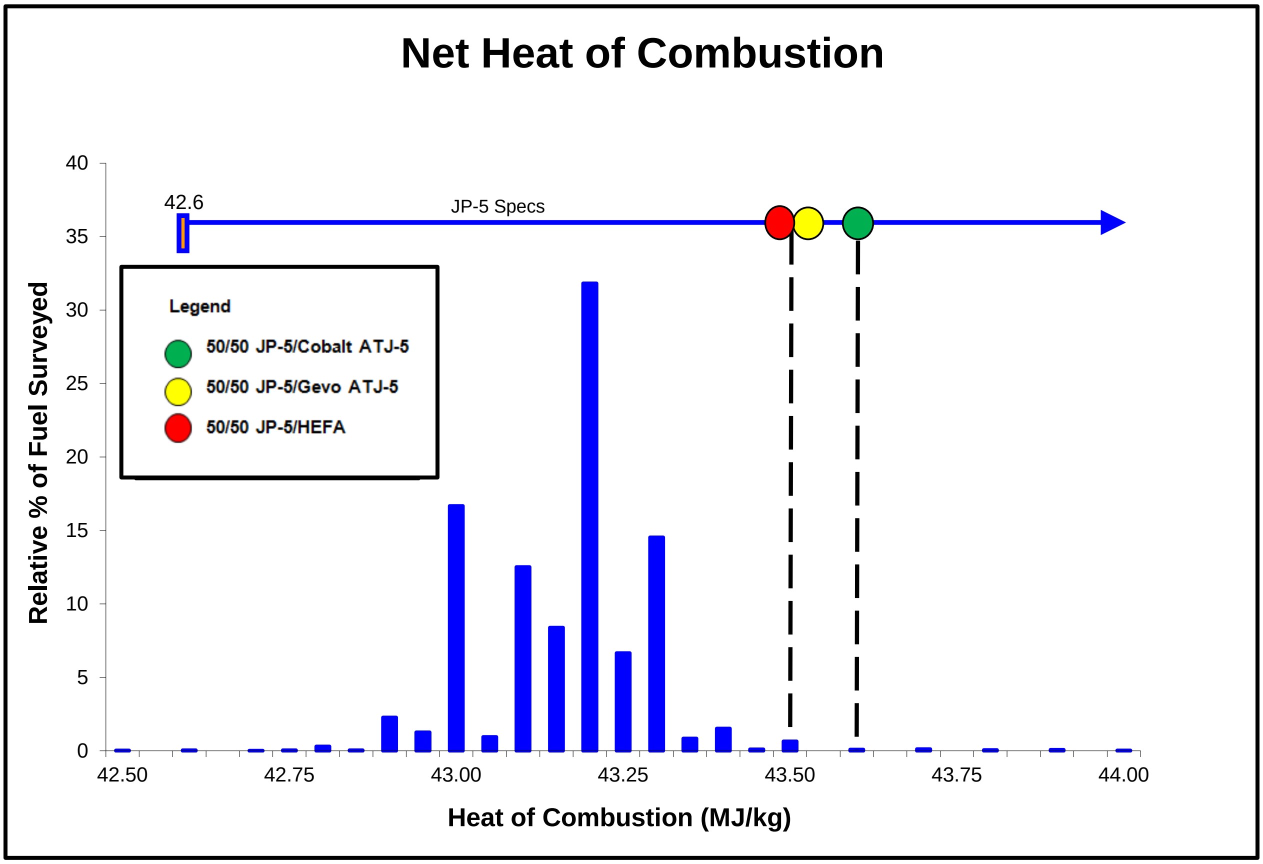

Figure 5. Heat of Combustion (by mass) of 50/50 JP5/Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 compared to 50/50 JP5/HEFA[2] and Historical JP5 data

Mass heat of combustion for the ATJ-5 blends was higher than the minimum specification limit of 42.6 MJ/kg. Figure 5 shows that the ATJ-5 blends were near the highest levels of mass heat of combustion for JP-5 fuels procured from 1990-2012. The heat of combustion values for the ATJ-5 blends were within the range of 50/50 JP5/HEFA which has undergone extensive specification, FFP, engine testing, and flight tests [5, 6, 7, 8, 9].

3.3 Fit-for-Purpose Level I Test Results

The Fit-for-Purpose Level I test results for the base petroleum fuel, Cobalt and Gevo ATJ-5 fuels and blends are summarized in Tables 4 -5 and Figures 6-9. FFP Level I test results from the ASTM commercial qualification effort included: simulated distillation, response to corrosion inhibitor/ lubricity improver additive, and response to static dissipator additive. For more detailed information regarding these tests, please reference the "Evaluation of Bio-Derived Alcohol to Jet Synthetic Paraffinic Kerosenes (ATJ-SPKs)" ASTM research report[10].

The 50/50 JP5/Cobalt ATJ5 blend passed all FFP Level 1 property requirements as defined in the SWP 44FL-006 with the exception of total alkali metal and metalloid content. The high metal content was due to a high silicon concentration in the petroleum JP-5. The neat Cobalt ATJ-5 failed the peroxide storage stability requirement because antioxidants were not originally added to this fuel; however upon blending neat Cobalt ATJ-5 with petroleum JP-5, this FFP property was brought within the acceptance criteria. The 50/50 JP5/Gevo ATJ5 blend passed all FFP Level 1 properties with the exception of cetane number. The low cetane number was due to the fact that the cetane value for neat Gevo ATJ-5 was significantly lower than typical JP-5. In some instances, the reported property value of 50/50 ATJ blends were outside the bounds of the neat ATJ and JP-5 values, but these discrepancies were within the experimental error of the test method and can be considered not significant.

Both Gevo and Cobalt blends failed the viscosity at -40°C property requirement. The viscosity at -40°C for both JP5/ATJ5 blends was higher than the maximum acceptance criteria of 12.0 mm^2/s. However, the viscosity at -20°C for both JP5/ATJ5 blends met the specification requirement of less than 8.5 mm^2/s. A limited survey of JP-5's showed some petroleum JP-5s exceed this limit as well. Additional investigation is underway to determine the appropriate maximum viscosity at -20°C for petroleum JP-5 and ATJ blends. For further discussion, see page 17.

As a reference, 50/50 JP5/HEFA data is also shown for comparison in the FFP Level I figures where appropriate, since it has successfully completed qualification and was incorporated into the JP-5 specification.

Table 4. Fit-for-purpose Level I Test Results for Cobalt ATJ-5, 50/50 JP5/Cobalt ATJ5, and Petroleum JP-5

Property	Test Method	Acceptance Criteria		Cobalt ATJ-5	50/50 JP-5/Cobalt ATJ-5 Blend	JP-5
		Min	Max			
Chemistry and Composition Properties						
Aromatics						
FIA (Volume %), or	ASTM D1319	8.0	25.0	Not Detected	9.9	19
HPLC (Volmue %)	ASTM D6379	8.4	26.5	Not Detected	13.0	24.3
Naphthalenes (Weight %)	ASTM D1840		3.0	0.0	0.9	1.6
Nitrogen Content (mg/kg)	ASTM D4629	Conform		2	5	8
Trace Copper (µg/kg)	ASTM D6732		20	3	4	5
Metals (mg/kg)	ASTM D711					
Ag				< 0.1	< 0.1	< 0.1
Al				< 0.1	< 0.1	< 0.1
Ca				< 0.1	< 0.1	< 0.1
Cd				< 0.1	< 0.1	< 0.1
Cr				< 0.1	< 0.1	< 0.1
Fe				< 0.1	< 0.1	< 0.1
Mg				< 0.1	< 0.1	< 0.1
Mn				< 0.1	< 0.1	< 0.1
Mo				< 0.1	< 0.1	< 0.1
Ni				< 0.1	< 0.1	< 0.1
P				< 0.1	0.1	0.1
Pb				< 0.1	< 0.1	< 0.1
Sn				< 0.1	< 0.1	< 0.1
Ti				< 0.1	< 0.1	< 0.1
V				< 0.1	< 0.1	< 0.1
Zn				< 0.1	< 0.1	< 0.1
Total Metals (mg/kg)			0.5	< 0.1	0.1	0.1
Alkali Metals & Metalloids (mg/kg)	ASTM D711					
B				0.1	0.3	0.2
Ba				< 0.1	< 0.1	< 0.1
Na				< 0.1	0.2	0.1
K				< 0.1	< 0.1	0.1
Si				0.7	1.2	1.6
Li				< 0.1	< 0.1	< 0.1
Total (mg/kg)			1.0	0.9	1.6	2.0
Existent Hydroperoxides	ASTM D3703		8	1	0	1
Bulk Physical and Performance Properties						
Fuel & Additive Compatability	ASTM D4054, Annex 2	Conform		PASSED	PASSED	PASSED
Lube Oil Compatability	In-House Method (Appendix A-4)[f]	Conform		PASSED	PASSED	PASSED
Distillation T50-T10 (°C)	ASTM D86	15		17	18	18
Distillation T90-T10 (°C)	ASTM D86	40		49	49	42
Interfacial Tension (dynes/cm)	ASTM D971	20		47	41	36
Volumetric Heating Value (MJ/L)	ASTM D4809	33.5		34.3	34.7	34.8
Viscosity @ -40°C (mm^2/s)	ASTM D445		12.0	23.9	15.7	11.6
Pour Point (°C)	ASTM D97		-56	<-75	-66	-57
Thermal Oxidative Breakpoint (°C)	ASTM 3241	Conform		>340	320	290
Lubricity, BOCLE Wear Scar (mm)	ASTM 5001		0.65	0.65	0.58	0.57
Lubricity, HFRR Wear Scar (µm)	ASTM 6079	Conform		680	690	730
Autoignition Temperature (°C)	ASTM E659	226.7		209.0	229.0	239.0
Cetane Number Derived	ASTM D6890	42		49	46	44
Storage Stability (Antioxidant; Δ mg/kg)	In-House Method (Appendix A-7)[f]	Conform		0	-2	-10
Storage Stability (Gums; mg/100mL)			7	0	0	1
Storage Stability (Peroxides; mg/kg)			16	693	3	4
Water Solubility @ 30°C (mg/kg)	In-House Method (Appendix A-8)[f]	Conform		76	80	124

Conform: Test fuel has a similar response to that of conventional fuels, falls within the range of experience measured for conventional fuels, demonstrates similar or improved characteristics when compared to typical JP-5 fuel, or falls within the bounds of Fit-for-Purpose acceptance criteria.

[f] Standard Work Package (SWP44FL-006): Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/ Fuel Sources

**Values highlighted in red denote 50/50 blend properties that do not meet FFP requirements*
*** Values highlighted in blue denote blend limiting properties*

Table 5. Fit-for-purpose Level I Test Results for Gevo ATJ-5, 50/50 JP5/Gevo ATJ5, and Petroleum JP-5

Property	Test Method	Acceptance Criteria		Gevo ATJ-5	50/50 JP-5/Gevo ATJ-5 Blend	JP-5
		Min	Max			
Chemistry and Composition Properties						
Aromatics						
FIA (Volume %), or	ASTM D1319	8.0	25.0	**Not Detected**	11	18
HPLC (Volume %)	ASTM D6379	8.4	26.5	**1.6**	11.0	17.1
Naphthalenes (Weight %)	ASTM D1840		3.0	0.0	0.7	1.5
Nitrogen Content (mg/kg)	ASTM D4629	Conform		1	4	9
Trace Copper (µg/kg)	ASTM D6732		20	3.7	3.2	1.2
Metals (mg/kg)	ASTM D7111					
Ag				< 0.1	< 0.1	< 0.1
Al				< 0.1	< 0.1	< 0.1
Ca				< 0.1	< 0.1	< 0.1
Cd				< 0.1	< 0.1	< 0.1
Cr				< 0.1	< 0.1	< 0.1
Fe				< 0.1	< 0.1	< 0.1
Mg				< 0.1	< 0.1	< 0.1
Mn				< 0.1	< 0.1	< 0.1
Mo				< 0.1	< 0.1	< 0.1
Ni				< 0.1	< 0.1	< 0.1
P				< 0.1	0.1	< 0.1
Pb				< 0.1	< 0.1	< 0.1
Sn				< 0.1	< 0.1	< 0.1
Ti				< 0.1	< 0.1	< 0.1
V				< 0.1	< 0.1	< 0.1
Zn				< 0.1	< 0.1	< 0.1
Total Metals (mg/kg)			0.5	< 0.1	0.1	< 0.1
Alkali Metals & Metalloids (mg/kg)	ASTM D7111					
B				0.1	< 0.1	< 0.1
Ba				< 0.1	< 0.1	< 0.1
Na				< 0.1	< 0.1	< 0.1
K				0.1	< 0.1	< 0.1
Si				< 0.1	0.1	0.4
Li				< 0.1	< 0.1	< 0.1
Total (mg/kg)			1.0	0.2	0.1	0.4
Existent Hydroperoxides	ASTM D3703		8	0	0	0
Bulk Physical and Performance Properties						
Fuel & Additive Compatability	ASTM D4054, Annex 2	Conform		PASSED	PASSED	PASSED
Lube Oil Compatability	In-House Method (Appendix A-4)[g]	Conform		PASSED	PASSED	PASSED
Distillation T50-T10 (°C)	ASTM D86	15		18	18	17
Distillation T90-T10 (°C)	ASTM D86	40		61	53	42
Interfacial Tension (dynes/cm)	ASTM D971	20		50	40	40
Volumetric Heating Value (MJ/L)	ASTM D4809	33.5		34.3	34.5	34.9
Viscosity @ -40°C (mm^2/s)	ASTM D445		12.0	**19.5**	**14.0**	11.3
Pour Point (°C)	ASTM D97		-56	-75	-72	-60
Thermal Oxidative Breakpoint (°C)	ASTM 3241	Conform		>340	280	285
Lubricity, BOCLE Wear Scar (mm)	ASTM 5001		0.65	0.40	0.48	0.50
Lubricity, HFRR Wear Scar (µm)	ASTM 6079	Conform		660	590	570
Autoignition Temperature (°C)	ASTM E659	226.7		>275.0	238.0	235.0
Cetane Number Derived	ASTM D6890	42		17	37	43
Storage Stability (Antioxidant; Δ mg/kg)	In-House Method (Appendix A-7)[f]	Conform		0	-4	-12
Storage Stability (Gums; mg/100mL)			7	19	4	0
Storage Stability (Peroxides; mg/kg)			16	1	4	3
Water Solubility @ 30°C (mg/kg)	In-House Method (Appendix A-8)[g]	Conform		77	71	86

Conform: Test fuel has a similar response to that of conventional fuels, falls within the range of experience measured for conventional fuels, demonstrates similar or improved characteristics when compared to typical JP-5 fuel, or falls within the bounds of Fit-for-Purpose acceptance criteria.

[g] Standard Work Package (SWP44FL-006): Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/ Fuel Sources

**Values highlighted in red denote 50/50 blend properties that do not meet FFP requirements*
*** Values highlighted in blue denote blend limiting properties*

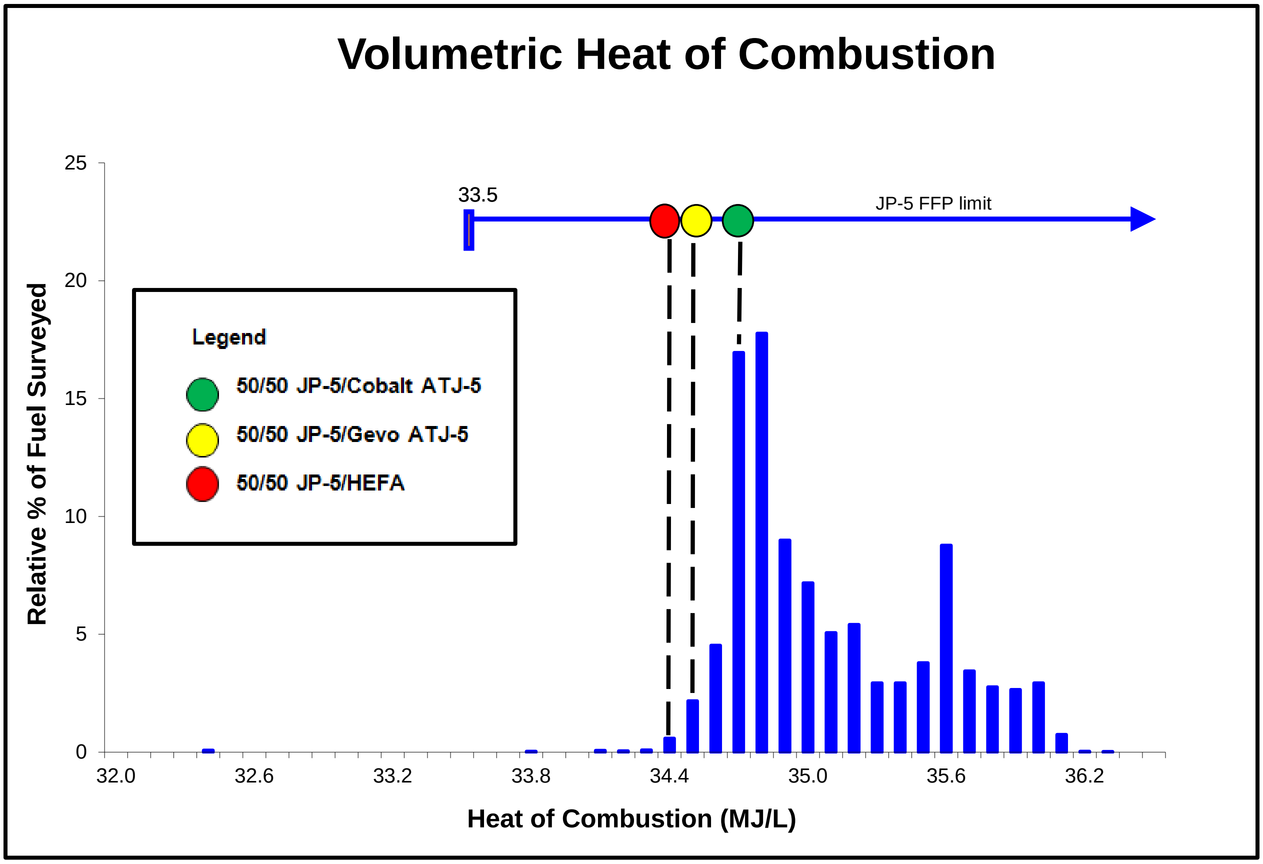

Figure 6. Heat of Combustion (by volume) of 50/50 JP5/Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 compared to 50/50 JP5/HEFA[2] and Historical JP-5 data

Volumetric heat of combustion, shown above in Figure 6, was near the low end of the conventional JP-5 fuels, but higher than 50/50 JP5/HEFA fuels and within the fit for purpose limits of 33.5 MJ/L. The lower volumetric heat of combustion was attributed to the density of ATJ-5 being lower than typical petroleum JP-5. This trend with volumetric heat of combustion for the ATJ-5 blends was very similar to the trend experienced with 50/50 JP5/HEFA. Despite the HEFA blend having a slightly lower heat of combustion, all engine testing to date with 50/50 JP5/HEFA has not shown any negative impact to operational performance[5,6,7,8,9,11]. ATJ-5 blends had a higher volumetric heat of combustion than the 50/50 JP5/HEFA blend; therefore ATJ-5 blends should perform no worse than HEFA blends previously tested.

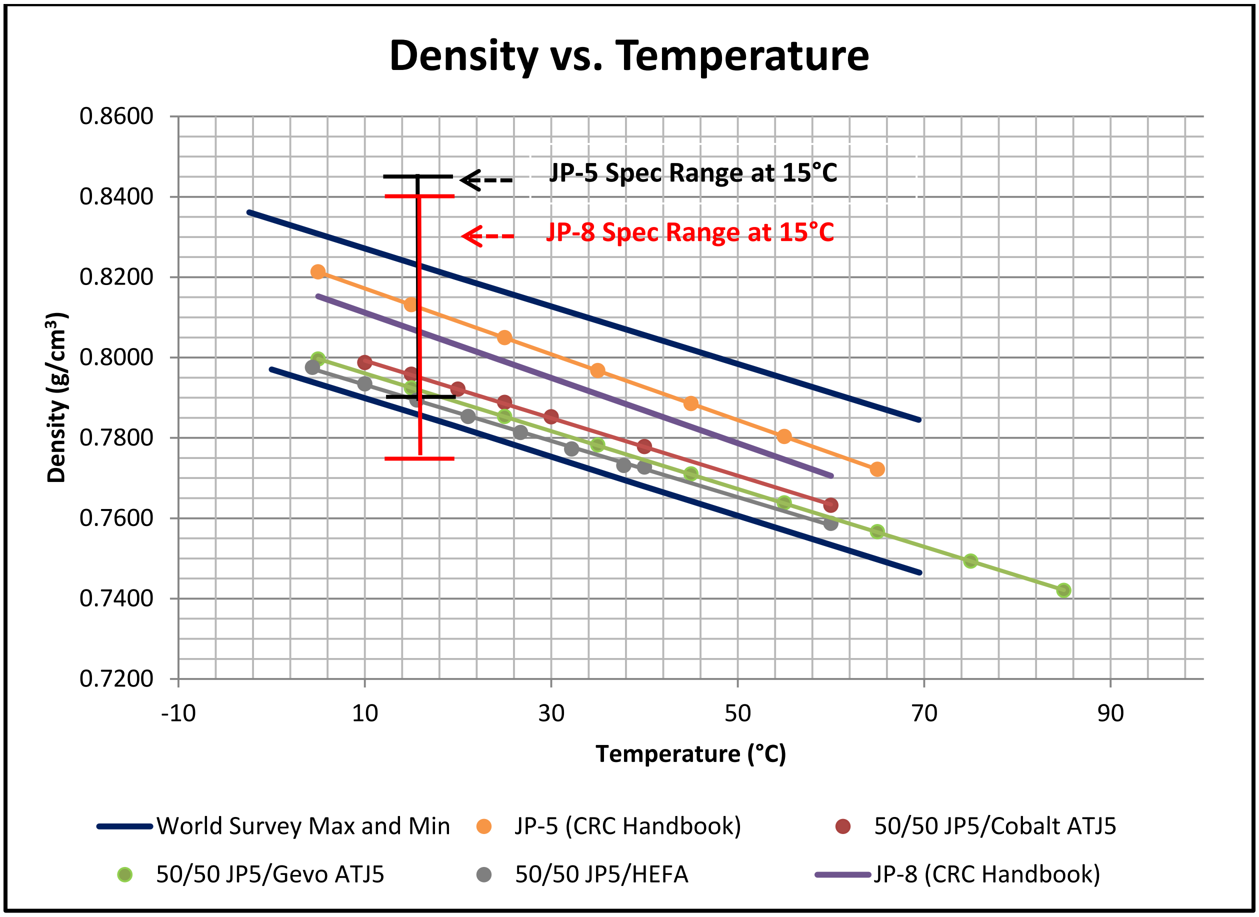

Figure 7. Density vs. Temperature graph of 50/50 JP5/Cobalt ATJ5, and 50/50 JP5/Gevo ATJ5 compared to neat JP-5, neat JP-8 and 50/50 JP5/HEFA [2, 10, 12, 13]

Fuel density affects loaded aircraft weight, fuel metering, fuel gauging, and operational range. Aircraft operate at large temperature ranges on the ground and during flight[14]. Since density of conventional turbine fuel is known to decrease linearly with increasing temperature, the density of the 50/50 ATJ blends were tested over a range of temperatures to ensure a similar response. Figure 7 shows the response of density to temperature for the 50/50 JP5/ATJ5 blends compared to JP-5, and the 50/50 JP8/Gevo ATJ8 compared to JP-8. Additionally, 50/50 JP5/HEFA was included for comparison.

The results in Figure 7 show that the density of the 50/50 JP5/ATJ5 blends fell within the World Sampling Program range[15], and as expected more closely aligned to 50/50 JP5/HEFA than petroleum-derived JP-5. The 50/50 JP5/ATJ5 blends exhibited the same rate of density decrease with temperature as the petroleum derived JP-5 and 50/50 JP5/HEFA blend.

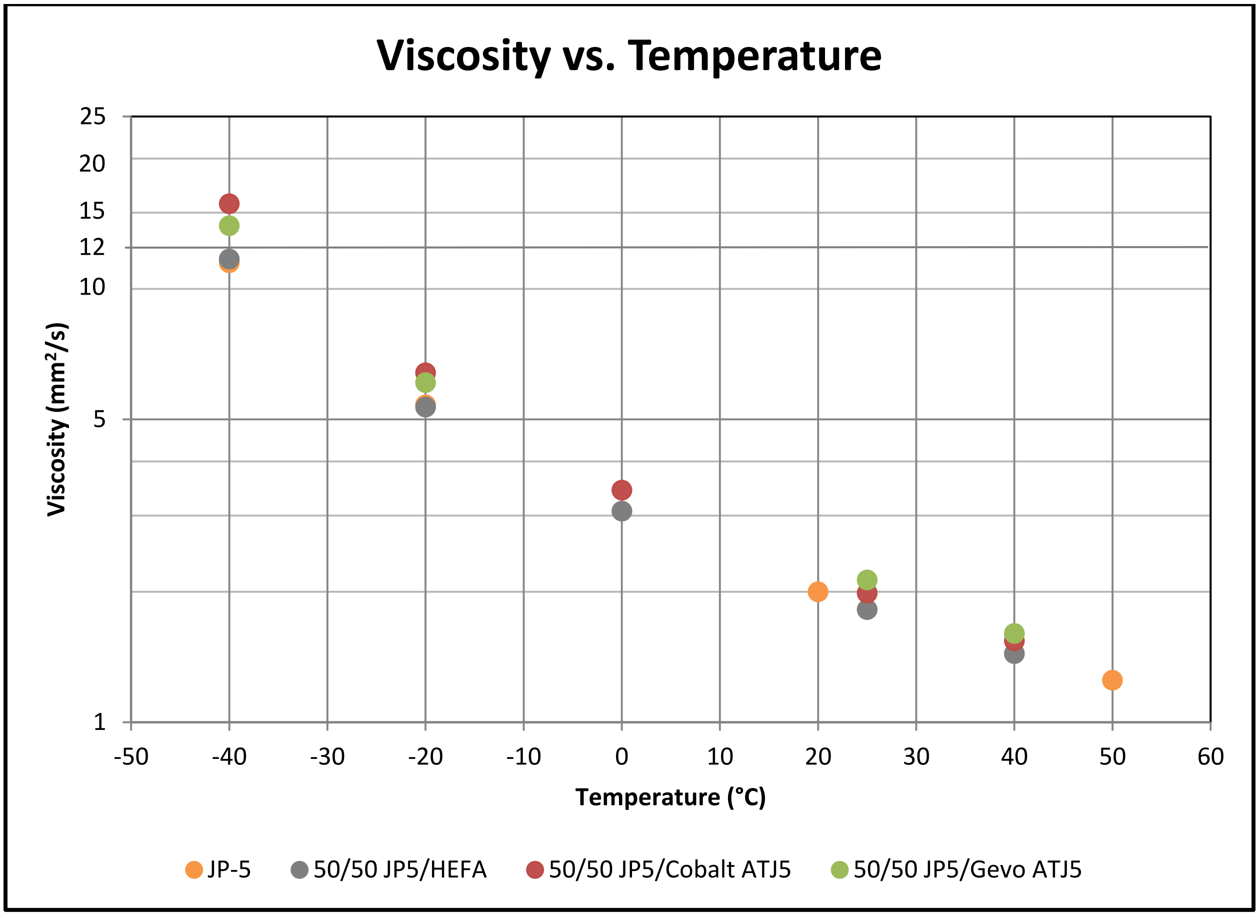

Figure 8. Viscosity vs. Temperature graph of 50/50 JP5/ Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 compared to JP-5 average from CRC Handbook and 50/50 JP5/HEFA [2, 10, 12, 13]

The kinematic viscosity of a fuel has an inverse response with temperature. This property is important for fuel system design as it affects pumping ability and fuel atomization.

The results in Figure 8 show that the kinematic viscosity of both 50/50 JP5/ATJ5 blends follow the typical viscosity response to temperature. The viscosity's response to temperature for the 50/50 JP5/ATJ5 blends, as indicated by the slope of the line, was similar to the average values for petroleum JP-5 reported in the CRC handbook JP-5.

The viscosity of the JP5/ATJ5 blends was higher than JP-5 and the 50/50 JP5/HEFA blend. The viscosity at -20°C for the ATJ5 blends met the JP-5 specification limit of 8.5 mm^2/s. The viscosity at -20°C for the 50/50 JP5/Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 blends were 6.4 mm^2/s and 6.1 mm^2/s respectively; however these values fall near the upper end of the normal range operating experience as seen in Figure 9. The viscosity at -40°C is a FFP criteria because most aircraft propulsion specifications cite a maximum fuel viscosity of 12 mm^2/s. However, an internal survey of five petroleum JP-5's in the past 5 years showed a viscosity at -40°C of 10.5 to 14.6 mm^2/s. A World Fuel Sampling Program of all grades of aviation turbine fuels found a range of viscosities at -40°C can range from 5.3-14.6 mm^2/s.[15] Given the possibility that petroleum JP-5's can meet the current specification requirement at -20°C and fail the fit for

purpose requirement at -40°C, it is difficult to fully assess the impact of ATJ blends that exceed 12 mm^2/s at -40°C. Additional work is being done to evaluate the cold temperature viscosity requirements of all aviation turbine fuels. When ATJ is incorporated into the JP-5 specification, the blending ratio will be adjusted to ensure that the blend is within the limits of historical JP-5 experience.

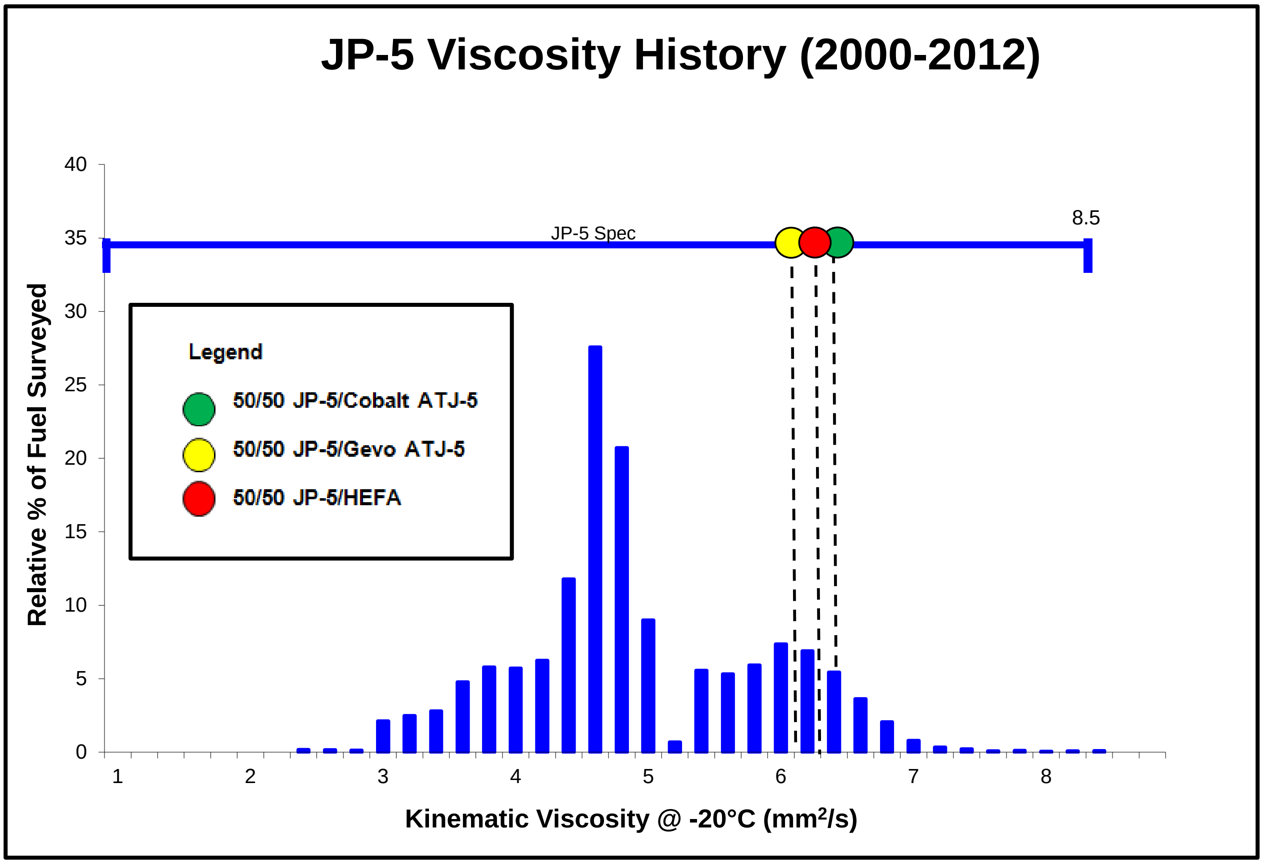

Figure 9. Viscosity at -20°C for 50/50 JP5/Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 compared to 50/50 JP5/HEFA[2] and Historical JP-5 data

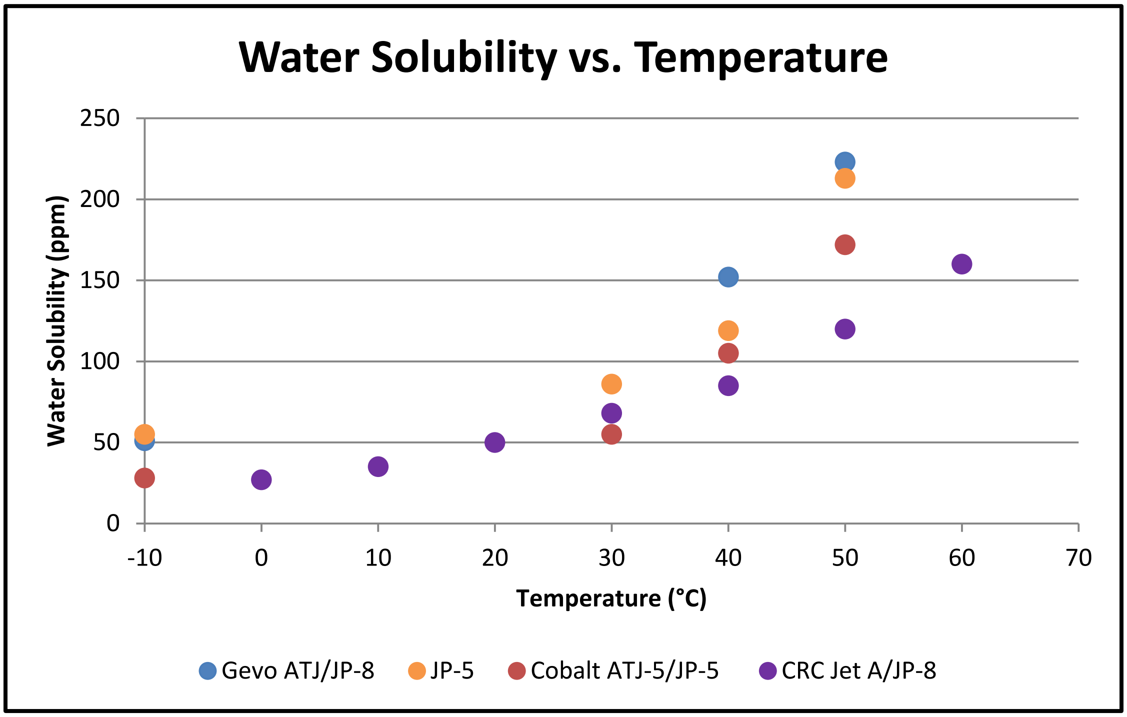

Figure 10. Water Solubility vs. Temperature for 50/50 JP8/Gevo ATJ and 50/50 JP5/Cobalt ATJ5 compared to neat JP-5 and CRC averages for Jet A and JP-8[12, 13]

Figure 10 shows the water solubility vs. temperature of the ATJ blends compared to neat JP-5 and averages of Jet A and JP-8 from the CRC handbook. High water content in fuels can have detrimental effects to the aircraft and fuel performance. Fuels with high water content are more susceptible to microbial growth and fuel system component corrosion. At low temperatures, the free water in the fuel will freeze and form blockages in the piping system of the aircraft. Salt water contamination can also cause hot section engine corrosion in the aircraft. The Gevo ATJ and the 50/50 JP5/Cobalt blend both follow the JP-5 water solubility response to temperature. The differences in the results are considered not significant since the water solubility response to temperature for the ATJ blends falls near the JP-5 trend.

Figure 11 and Figure 12 show the distillation curve of both batches of neat ATJ-5, 50/50 blends of ATJ-5 and JP-5, and neat JP-5. Additionally the 1990-2012 PQIS data (historical experience of all JP-5 procured for US Navy use) was plotted to show current range of JP-5 fuel distillation curves. Both the neat ATJ-5 and the JP5/ATJ5 blends had a distillation curve similar to JP-5 and were within the range of JP-5 PQIS data.

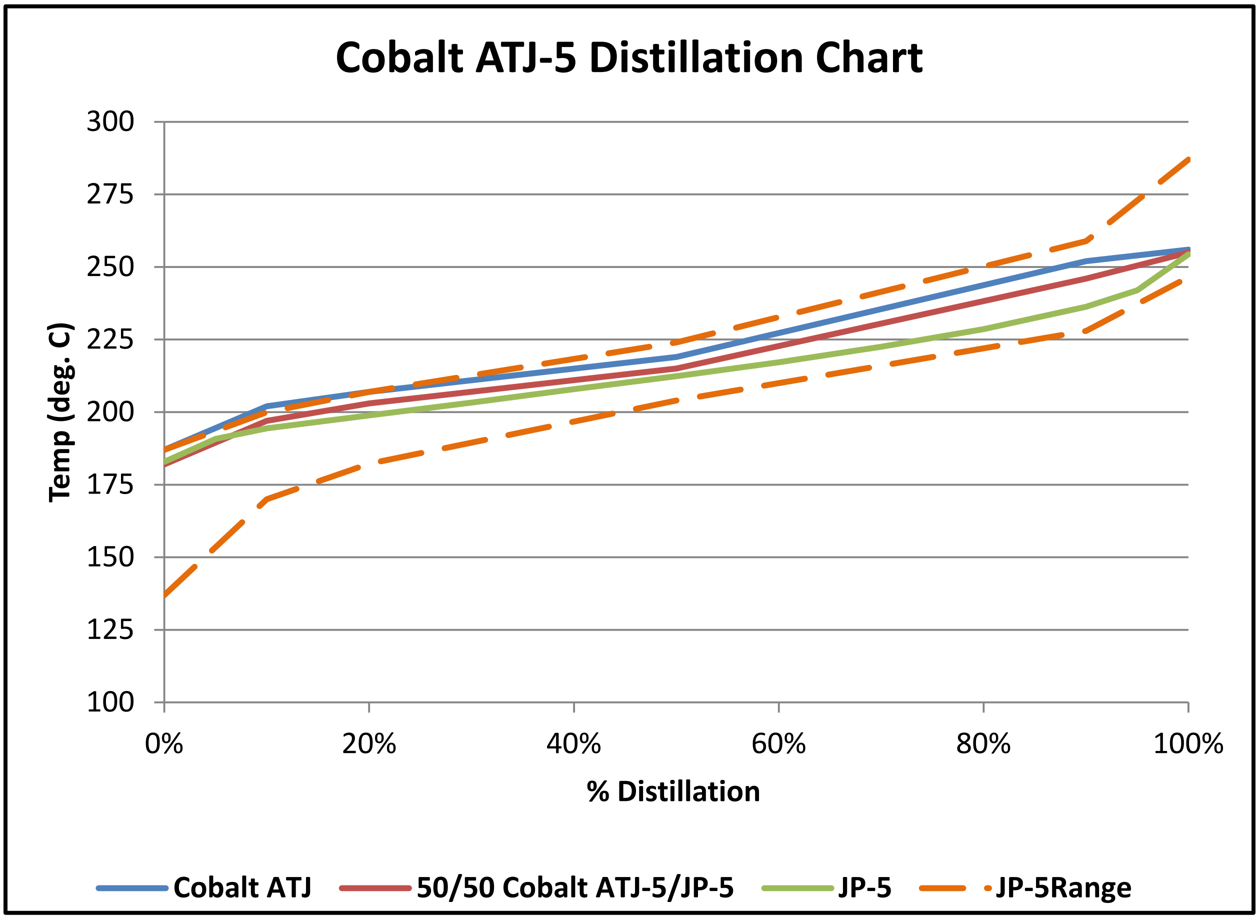

Figure 11. Distillation Curve of Cobalt ATJ-5, 50/50 JP5/ Cobalt ATJ5, and JP-5 compared to Historical JP-5 data

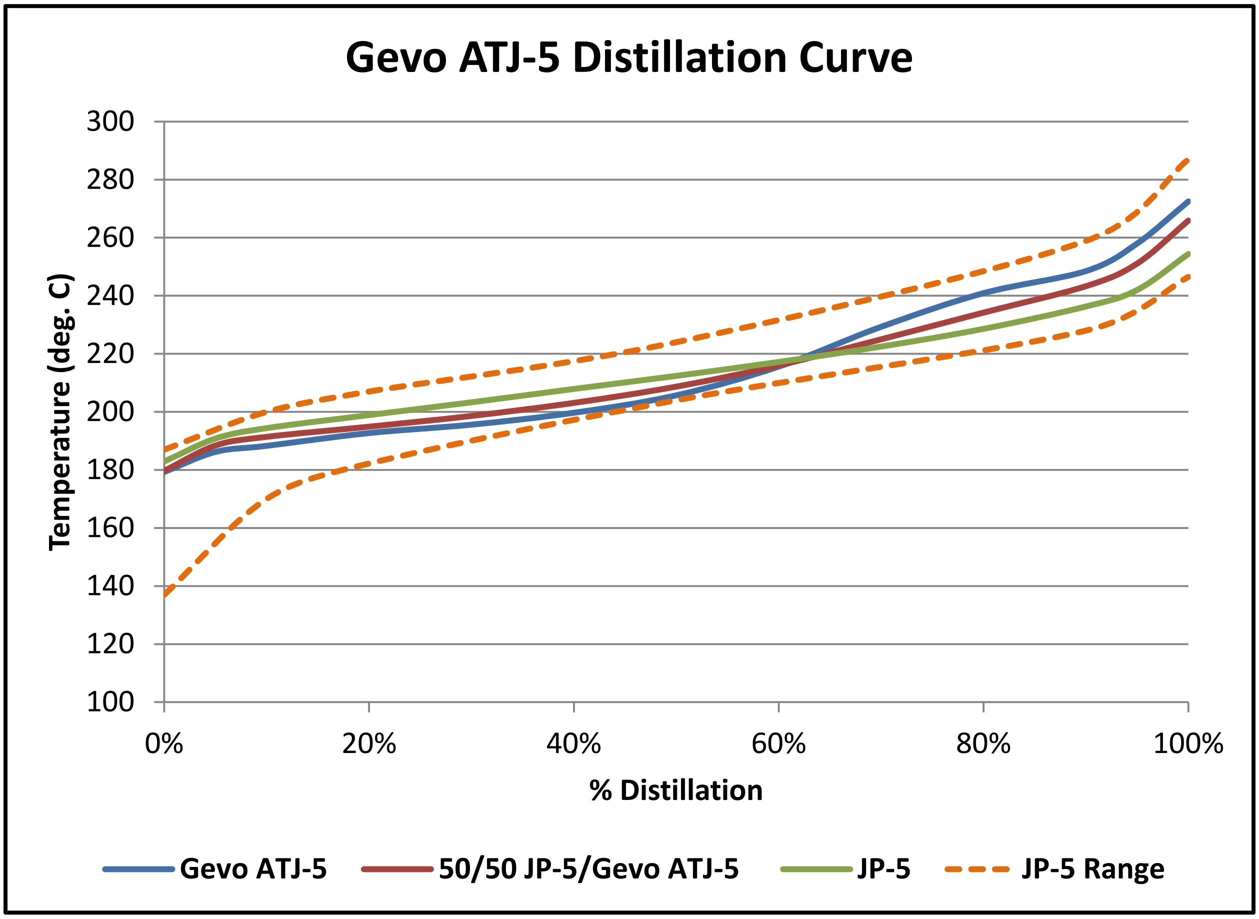

Figure 12. Distillation Curve of Gevo ATJ-5, 50/50 JP5/Gevo ATJ5, and JP-5 compared to Historical JP-5 data

3.3.1 Chemical Compositional Analysis

As part of the FFP, the chemical compositional profiles of neat Cobalt ATJ-5 and Gevo ATJ-5 were determined with the GC-MS. The GC-MS identifies and classifies the various chemical compounds present in the fuel. These results are represented in Figures 13 and 14 respectively. All compounds identified in the neat Cobalt ATJ-5 and Gevo ATJ-5 are of similar composition and molecular weight to hydrocarbons normally present in petroleum JP-5 petroleum fuels. When blended with conventional JP-5, a broader distribution of paraffinic and aromatic molecules is present in the Cobalt and Gevo blends similar to that of petroleum JP-5.

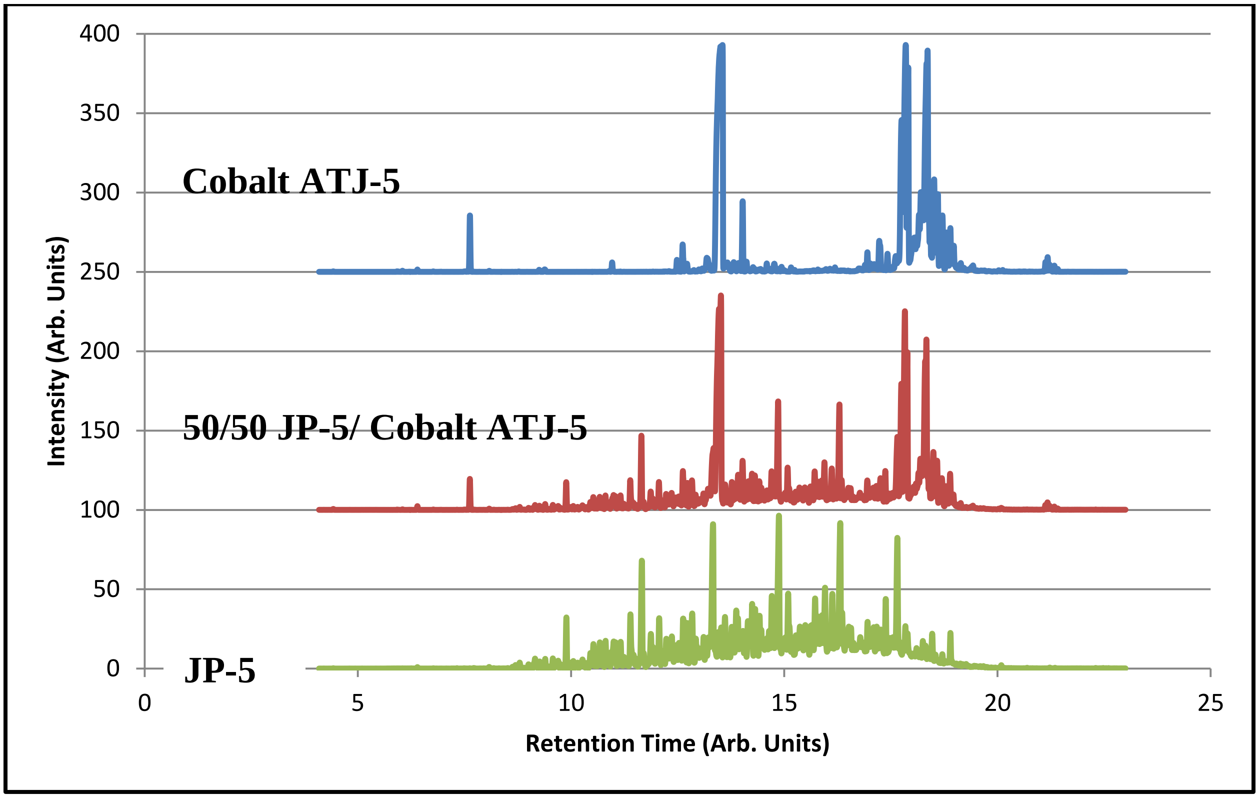

Figure 13. GC-MS of Neat Cobalt ATJ-5, 50/50 JP5/Cobalt ATJ5, and Neat JP-5

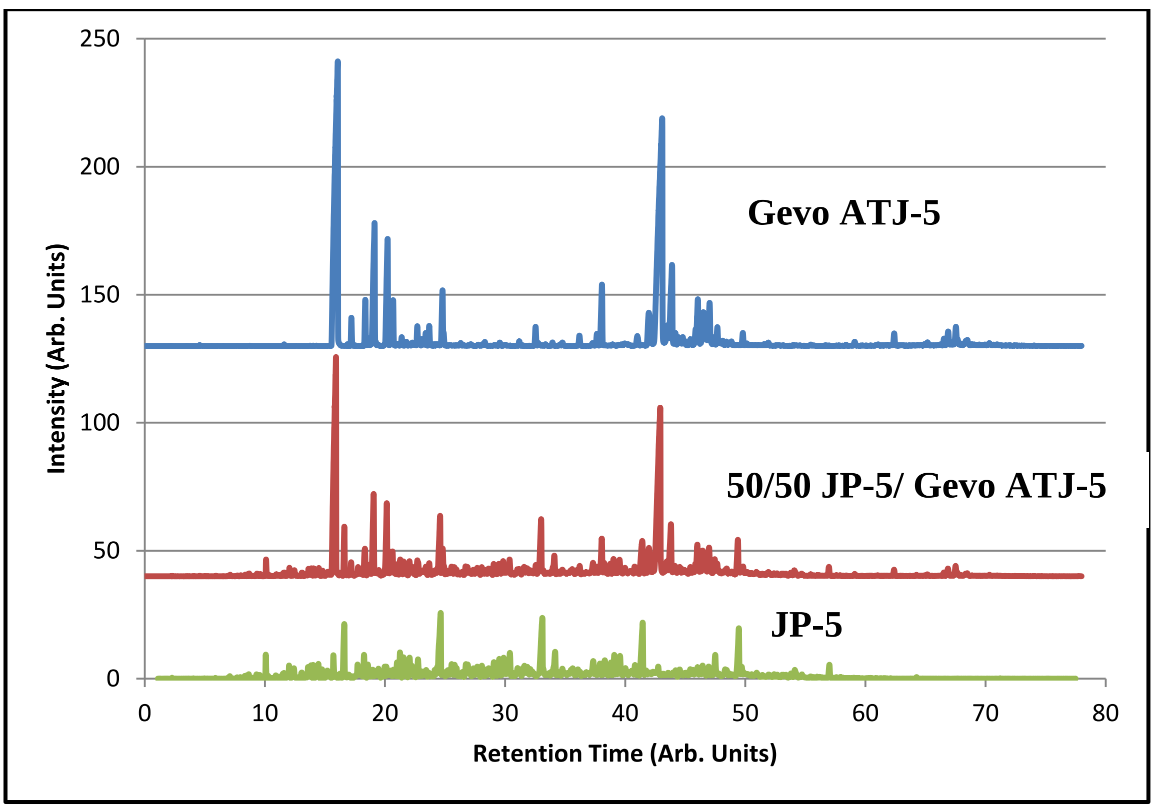

Figure 14. GC-MS of Neat Gevo ATJ-5, 50/50 JP5/Gevo ATJ5, and Neat JP-5

3.4 Fit-for-Purpose Level II Test Results

Fit-for-purpose Level II testing requires larger quantities of test fuel and longer testing time than Fit-for-purpose Level I testing. These tests not only address aviation performance properties, but focus on diesel combustion, safety, fuel handling, and materials compatibility characteristics. A complete list of all the FFP Level II requirements is outlined in Appendix C of this report. This report includes test results conducted as part of this program as well as results from testing conducted in support of the ASTM commercial approval process. Additionally other FFP Level II tests were waived due to similarity in chemistry with the 50/50 JP5/HEFA blend.

Navy FFP testing included: vapor pressure vs. temperature, dielectric constant vs. density, thermal conductivity vs. temperature, specific heat vs. temperature, surface tension vs. temperature, bulk modulus, and gas solubility. FFP test results from the ASTM commercial qualification effort included: hot surface ignition temperature, and flammability limits. For more detailed information regarding these tests, please reference the "Evaluation of Bio-Derived Alcohol to Jet Synthetic Paraffinic Kerosenes (ATJ-SPKs)" ASTM research report[10]. The following tests were waived for 50/50 JP5/ATJ: fuel system icing inhibitor additive test, and copper migration due to chemical similarity.

This section compares FFP Level II test results against JP-5 and 50/50 JP5/HEFA. 50/50 JP-8/ATJ8 blends were used for some testing because large volumes of ATJ-8 were available from the US Air Force while ATJ-5 was being procured. 50/50 JP8/ATJ8 testing was relevant to Navy aircraft because all Navy engines are approved to use JP-8 fuels without restriction. The main difference between the 50/50 JP5/Gevo ATJ5 blend and the 50/50 JP8/Gevo ATJ8 blend was the JP-8 blend had a lower viscosity and flash point. Excluding the difference in viscosity and flash point, the physical and chemical properties of the JP8/Gevo ATJ8 and JP5/Gevo ATJ5 blends were very similar. For some properties, JP-8 data was shown to demonstrate that the 50/50 JP5/ATJ5 or 50/50 JP8/ATJ8 blends performed similar to a neat petroleum fuel that is qualified for use in the U.S. Navy.

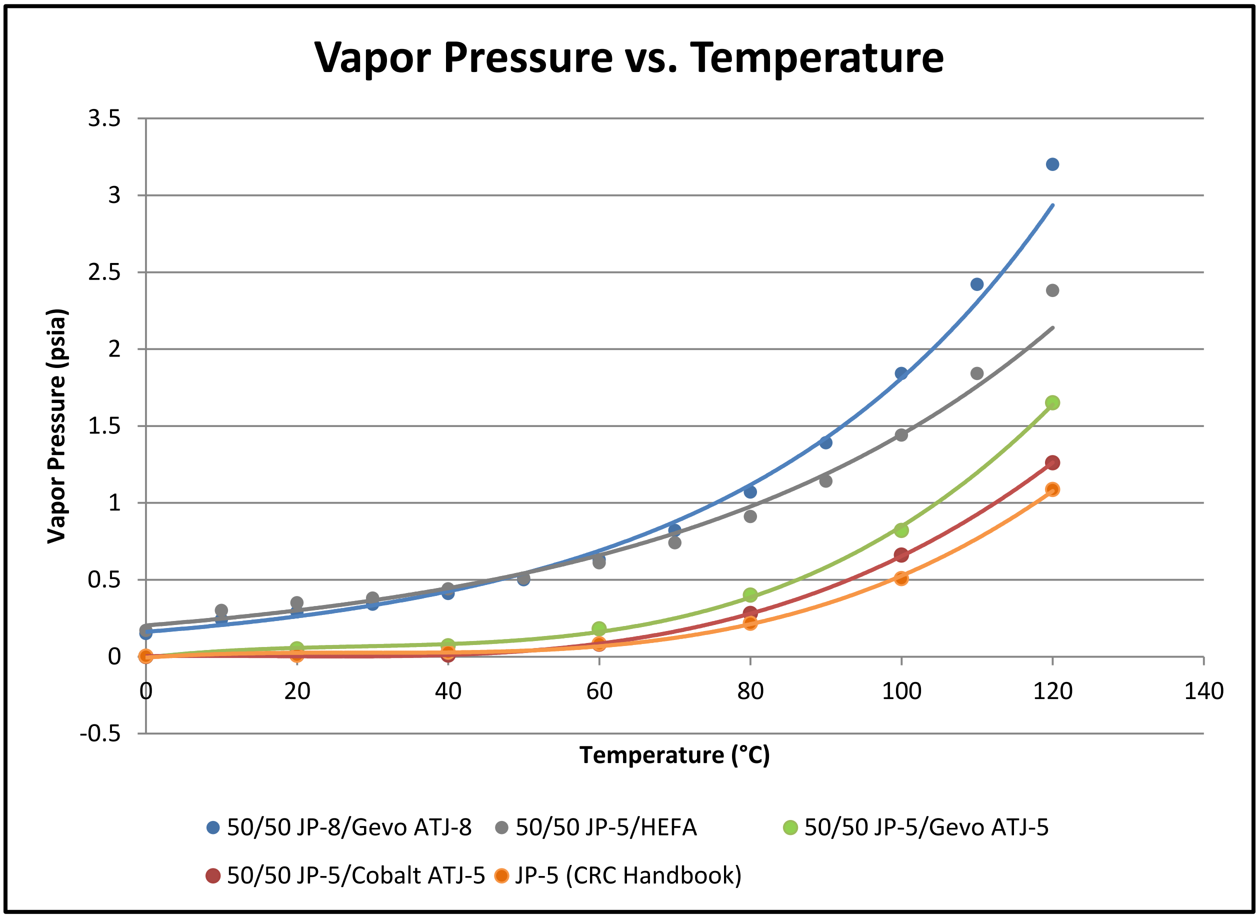

Figure 15. Vapor Pressure vs. Temperature graph of 50/50 JP5/Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 compared to JP-5 average from CRC Handbook and 50/50 JP5/HEFA [2, 10, 12, 13]

Vapor pressure is the pressure exerted by the vapor phase of a fuel when in equilibrium with the liquid phase at a given temperature. The risk of vapor lock (excessive vapor volume inside a fuel transfer pump which obstructs the flow of liquid fuel) increases with increasing fuel vapor pressure[14].

Figure 15 shows that the vapor pressure of the 50/50 ATJ blends is consistent with JP-5 vapor pressure values from the CRC Handbook of Aviation Fuel Properties (this reference will herein be referred to as the CRC Handbook). The JP5/ATJ5 blends increased with temperature in a similar parabolic manner to the CRC handbook typical values for JP-5. The vapor pressure response to temperature for the JP5/ATJ5 blends was lower than the 50/50 JP5/HEFA blend. Therefore the 50/50 JP5/ATJ5 blends should perform no worse than fuels that are currently approved in the JP-5 specification.

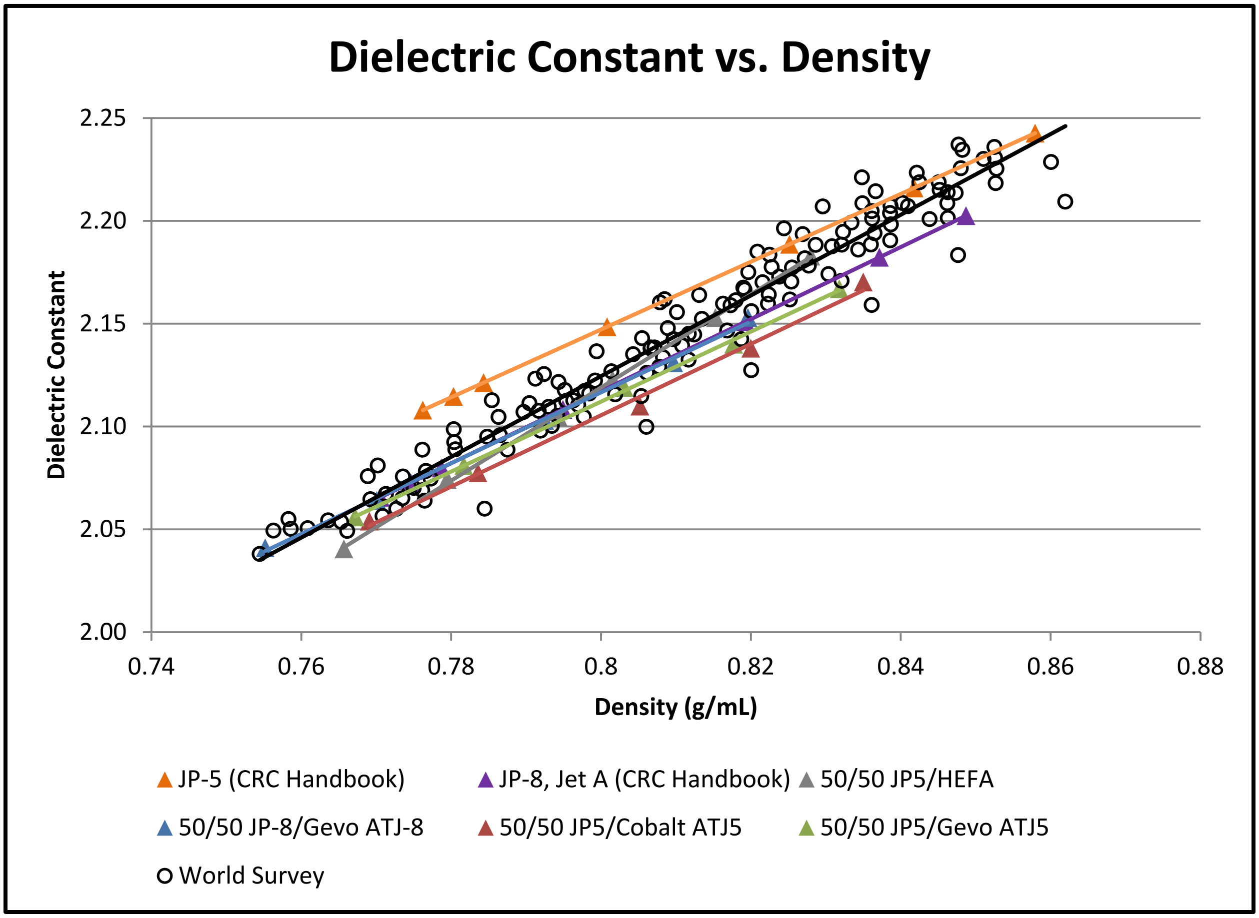

Figure 16. Dielectric Constant vs. Density graph of 50/50 JP8/Gevo ATJ8, 50/50 JP5/Cobalt ATJ5, and 50/50 JP5/Gevo ATJ5 compared to JP-5 and JP-8 averages from CRC Handbook, and 50/50 JP5/HEFA[2, 10, 12, 13]

The dielectric constant is defined as the electrical capacitance of a volume of fluid to the capacitance of an equivalent volume of air. Capacitance probes for fuel metering applications use the dielectric constant to gauge available quantities of fuel[14]. The dielectric constants for the 50/50 blends were tested over a range of fuel temperatures and densities.

Figure 16 and Figure 17 respectively show the dielectric constant vs. density and the dielectric constant vs. temperature of three 50/50 ATJ blends. The dielectric constant of all three 50/50 ATJ blends increased linearly with density. The dielectric constant response to density for the JP5/Cobalt ATJ-5 blend was the same, however at a given density, the dielectric constant was slightly lower than that of the World Fuel Sampling average trend line, but still above the minimum values analyzed in the survey[15]. The minor discrepancies between these results are within the experience of petroleum fuels[10]. For this comparison, the World Fuel Sampling data provides more applicable results than the CRC handbook because the World Fuel Sampling dielectric constant results are based on current quantitative experienced JP-5 values. The dielectric constant values for JP-5 from the CRC handbook are based on trends in average values for JP-5 and not specific quantitative values. The JP5/Gevo ATJ5 blend exhibited the same response and very similar magnitude as the World Fuel Sampling Average trend line.

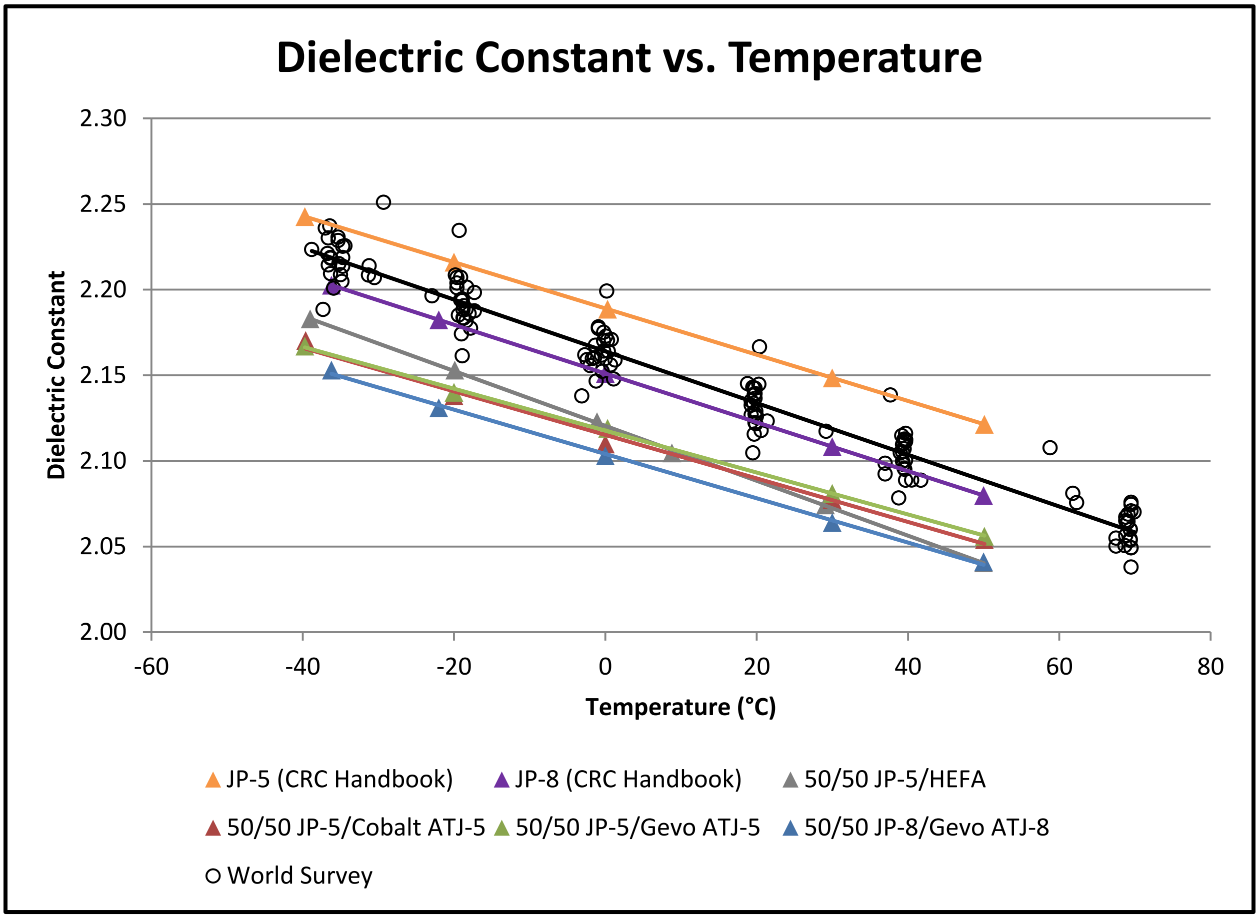

Figure 17. Dielectric Constant vs. Temperature graph of 50/50 JP5/Cobalt ATJ5, and 50/50 JP5/Gevo ATJ5 compared to neat JP-5, neat JP-8 and 50/50 JP5/HEFA[2, 10, 12, 13]

The three 50/50 ATJ blends showed an inverse relationship between temperature and the dielectric constant. All three blends were lower than the JP-5 and World Fuel Sampling Program response at all temperatures, but the response of the 50/50 ATJ blends was the same as JP-5 and the World Fuel Sampling Program average trendline. The dielectric constant response to temperature for the 50/50 JP5/Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 blends exhibited a response similar to 50/50 JP5/HEFA. At all temperature values, the dielectric constant of the 50/50 JP5/ATJ5 blends were consistent with the dielectric constant values for the JP5/HEFA blend.

The dielectric constant trends in density and temperature both correspond to trends previously identified in conventional petroleum fuels. Much like HEFA blends, ATJ blends also had a lower dielectric constant at a given temperature but the overall response (slope of the line) was the same. Experience with 50/50 JP5/HEFA has validated the lower dielectric constant. The dielectric constant of the 50/50 ATJ blends will respond in a similar manner with density and temperature change as petroleum-derived turbine fuels[2, 5, 6, 7, 8, 9].

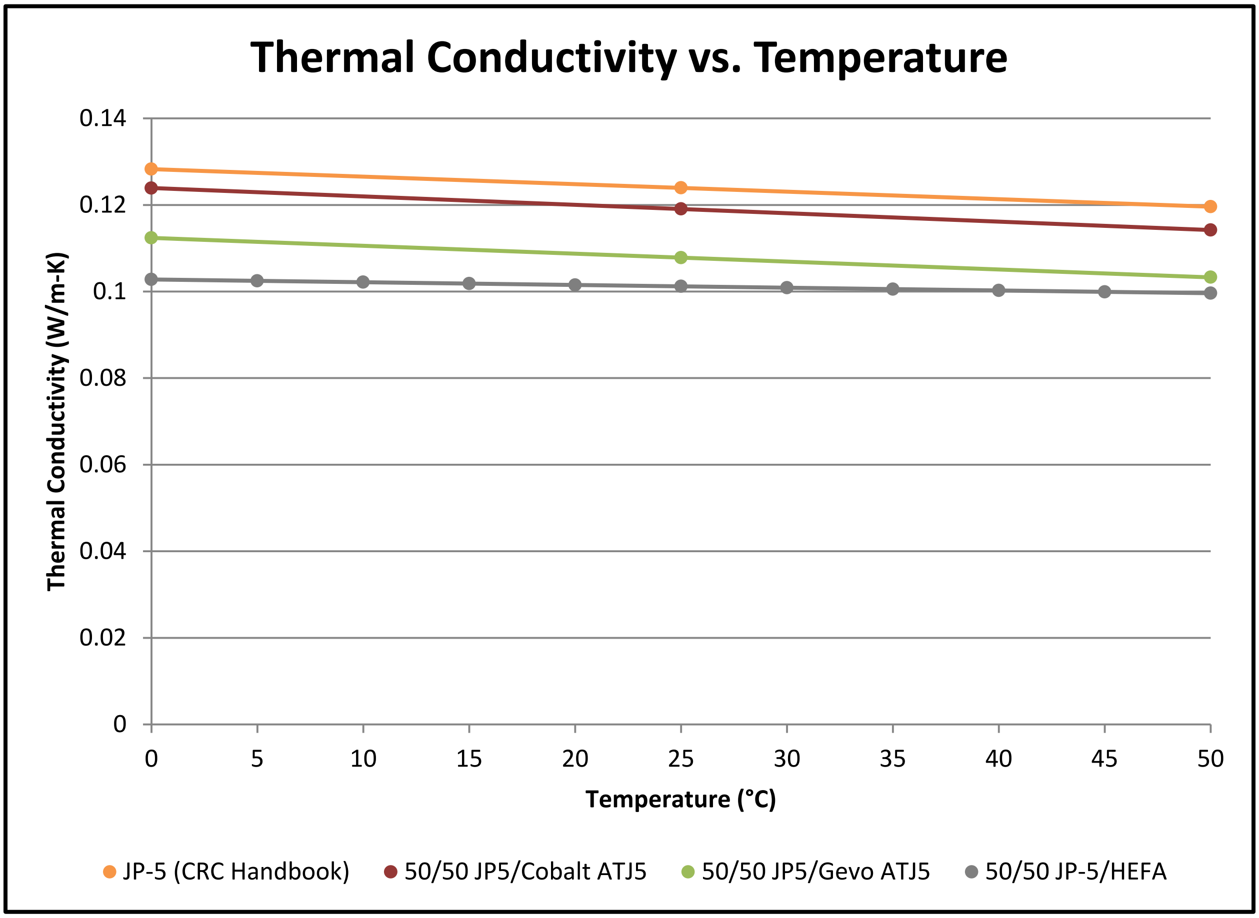

Figure 18. Thermal Conductivity of 50/50 JP5/Cobalt ATJ5, and 50/50 JP5/Gevo ATJ5 compared to JP-5 average from CRC Handbook and 50/50 JP5/HEFA[2, 10, 12, 13]

Thermal conductivity is a property that controls the rate at which heat is conducted through the fuel. It is used in heat transfer design calculations when fuel temperature is used as a heat sink in heat exchangers, when fuel is heated or cooled, or whenever there is a temperature gradient within the fuel[14].

The thermal conductivity response of the JP5/ATJ blends follows the typical thermal conductivity response to temperature and performed similar in manner to that of JP-5 as referenced in the CRC handbook. Figure 18 compares the thermal conductivity vs. temperature of 50/50 JP5/Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 to average JP-5 values from the CRC Handbook and 50/50 JP5/HEFA. 50/50 JP5/ Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 blends had a thermal conductivity versus temperature response similar to JP-5, but lower overall. The thermal conductivity at a given temperature for the JP5/Cobalt ATJ5 blend was about 10% lower than the neat JP-5. The thermal conductivity of the JP5/Gevo ATJ5 blend was about 3% lower than JP-5, but both blends had a thermal conductivity difference less than 50/50 JP5/HEFA. Therefore the 50/50 JP5/ATJ5 blends should perform no worse than fuels currently approved in the JP-5 specification.

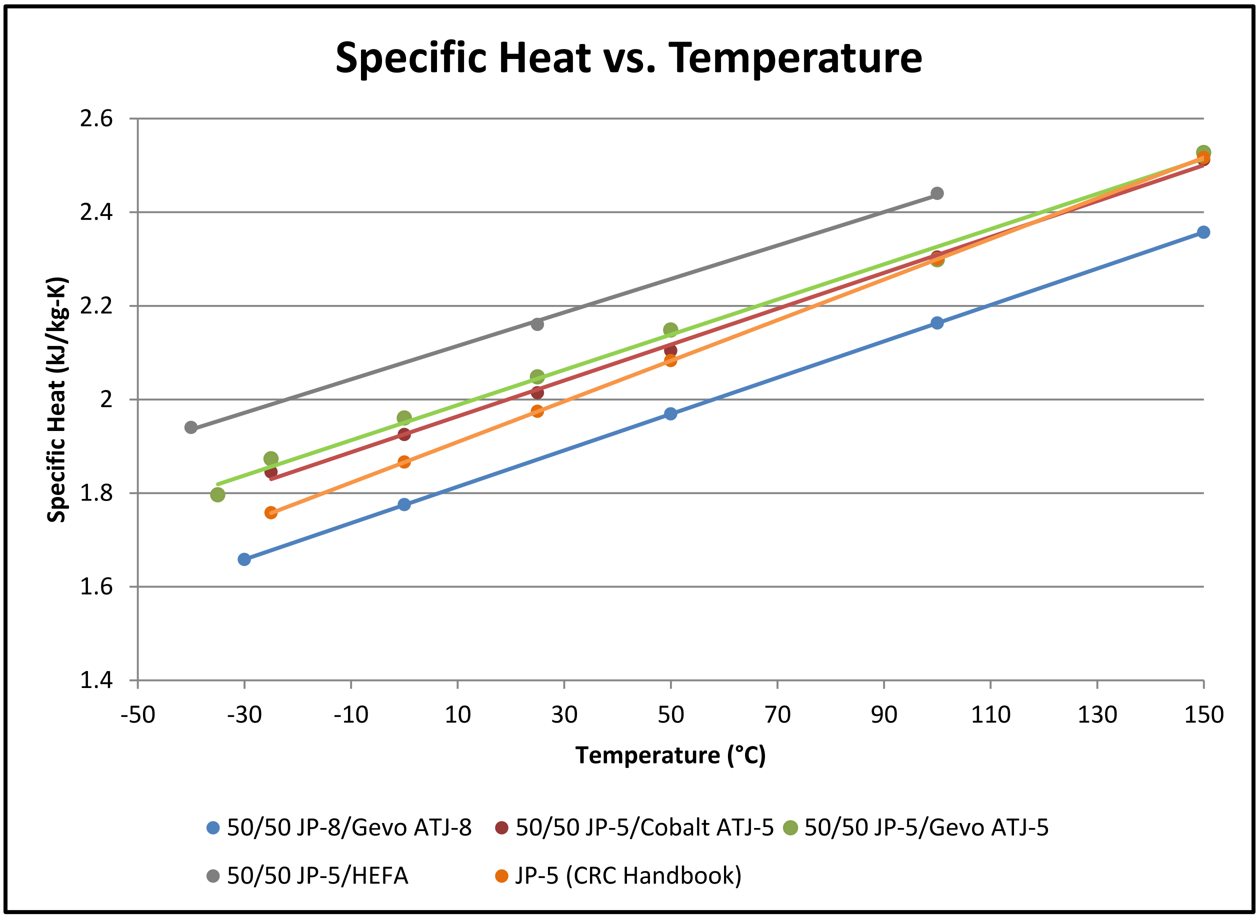

Figure 19. Specific Heat profile of 50/50 JP5/ Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 compared to neat JP-5 and 50/50 JP5/HEFA[2, 10, 12, 13]

The specific heat capacity of a fuel is the amount of heat energy transferred into or out of a unit mass of liquid fuel when increasing or decreasing its temperature. Specific heat capacity is important to fuel and other subsystem designs because fuel is used as a medium for heat exchange in aircraft. Higher specific heat per unit mass enhances a fuel's function as a heat transfer medium and presents low risk to negatively impacting aviation subsystem operation and performance[14].

The specific heat response for the JP5/ATJ blends follow the typical specific heat response to temperature for JP-5 as reported in the CRC handbook[12]. Figure 19 shows the specific heat capacities across a representative operational temperature range of the 50/50 ATJ blends. The JP5/Cobalt ATJ5 and JP5/GevoATJ5 blends had a specific heat capacity nearly identical to the average CRC handbook JP-5 values. The minor discrepancies between these results are within the experimental error of the method and can be considered not significant.

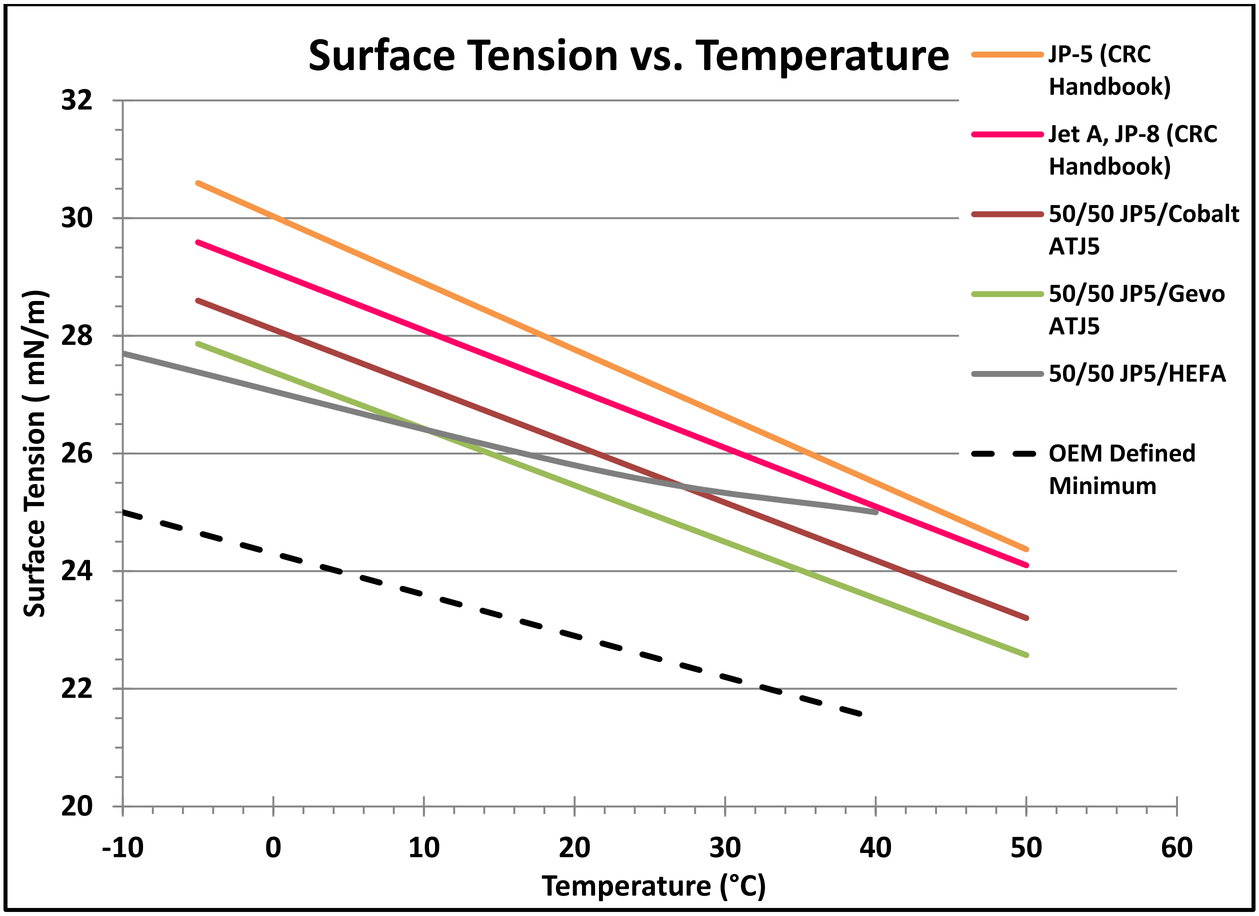

Figure 20. Surface Tension of 50/50 JP5/Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 compared to JP-5 and JP-8 averages from CRC Handbook, and 50/50 JP5/HEFA [2, 10, 12, 13, 16]

Surface tension is an important property in fuel atomization[17]. Surface tension of fuels decreases linearly as temperature increases. Measurements are taken across a large temperature range to ensure that the test fuel adheres to this linear trend and maintains adequate surface tension for fuel atomization.

Figure 20 shows the measured surface tensions of 50/50 JP5/Gevo ATJ5 and 50/50 JP5/Cobalt ATJ5 across a range of operational temperatures in comparison to CRC handbook data for Jet A, JP-8, and JP-5. The 50/50 JP5/ Cobalt ATJ5 and 50/50 JP5/Gevo ATJ5 blends had a surface tension versus temperature response similar to JP-5, but lower overall. The surface tension at a given temperature for the JP5/Cobalt ATJ5 blend was about 6% lower than the neat JP-5. The surface tension for the JP5/Gevo ATJ5 blend was about 9% lower than JP-5. The surface tension values of the 50/50 JP5/ATJ5 blends did not fall below the OEM-established minimum, [18] and linearly increased with decreasing temperature at the same rate than those of petroleum-based turbine fuels. These results show that the surface tension response to temperature is expected to be indistinguishable between the 50/50 ATJ blends and conventional JP-5.

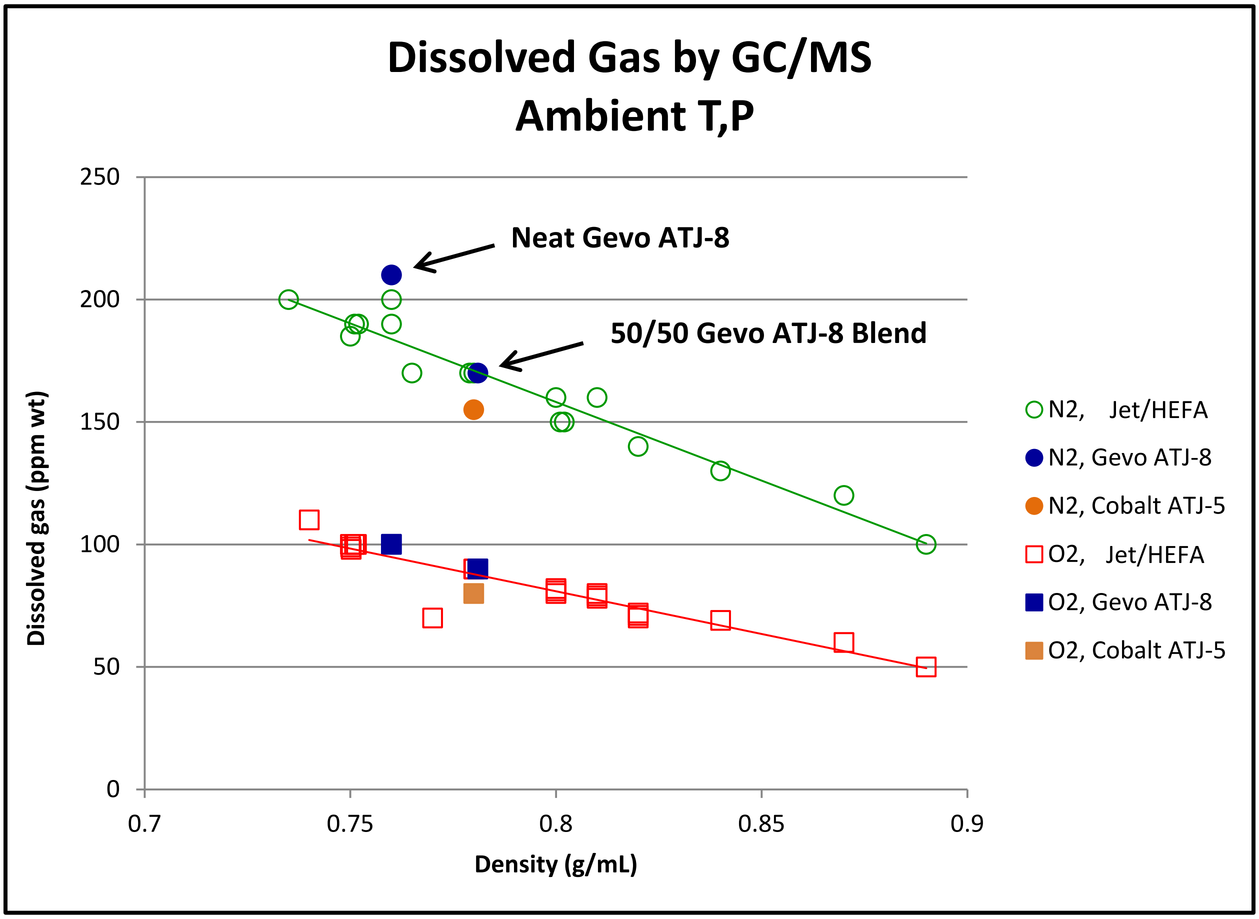

Figure 21. Gas Solubility in Cobalt ATJ-5 and Gevo ATJ-8[10]

Gas solubility is an important property for fuel systems. During aircraft climbing and air combat maneuvers, the aircraft can experience significantly reduced pressure. At reduced pressure, the dissolved nitrogen and/or oxygen will separate from the fuel and will form gas bubbles which can cause fuel pump cavitation[14].

Figure 21 shows the dissolved gas content of the neat Cobalt ATJ-5 and the Gevo ATJ-8. The oxygen content in the Cobalt and Gevo fuel falls within the range of experience for JP-5 and HEFA fuels. The nitrogen content for the neat Cobalt ATJ-5 was similar to JP-5 fuels; however the dissolved nitrogen content for neat Gevo ATJ-8 was higher than the expected values for similar fuels. This value was reduced upon blending with JP-5 and fell in line with the nitrogen content values for similar fuels. Figure 22 shows the dissolved air content of Cobalt ATJ-5 and Gevo ATJ-8 compared to HEFA fuels and neat JP-5. The trends as described for Figure 21 are also apparent in Figure 22.

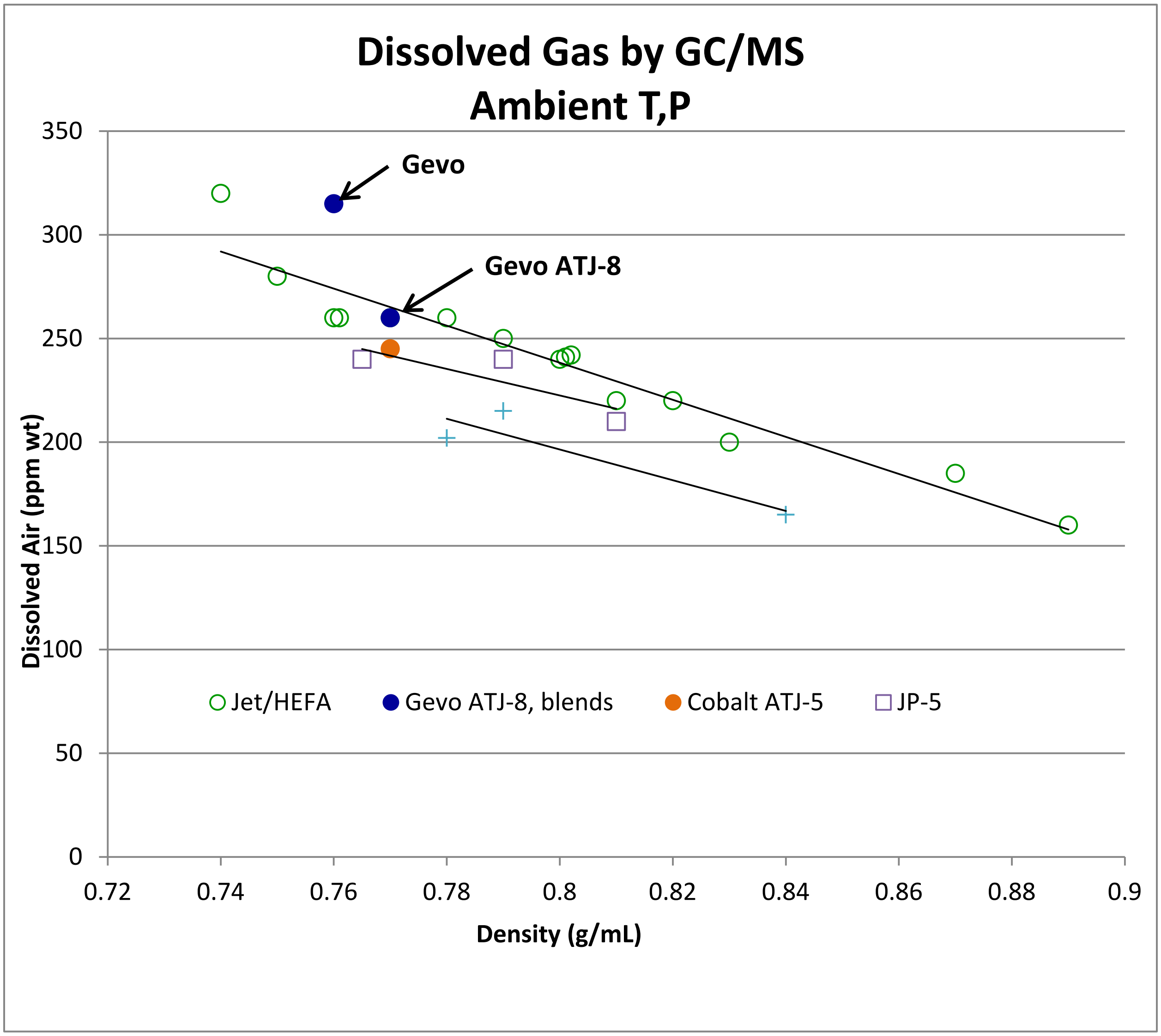

Figure 22. Dissolved Gas by GC-MS[10]

Table 6. Isentropic Bulk Modulus data for 50/50 JP-8/Gevo ATJ-8, 50/50 JP-5/ Cobalt ATJ-5, and 50/50 JP-5/Gevo ATJ-5 compared to neat JP-5, neat JP-8, and 50/50 JP5/HEFA[10, 12, 13, 15]

Fuel	Isentropic Bulk Modulus (at 30°C and 0 psi)
JP-5	198,563 psi
JP-8	189,064 psi
50/50 JP5/HEFA	185,326 psi
50/50 JP5/Cobalt ATJ5	182,443 psi
50/50 JP5/Gevo ATJ5	179,160 psi
50/50 JP8/Gevo ATJ8	169,233 psi

Bulk modulus is defined as the increase in pressure required to reduce fuel to a known volume. The bulk modulus is dependent on the speed of sound and density of a specific fluid. Bulk modulus is an important property for equipment that uses fuel to transfer energy and is significant for fuel gauges with ultrasonic probes[10]. Measurements of isentropic bulk modulus data points were obtained at a constant system pressure of 0 psi for 50/50 JP5/Cobalt ATJ5, 50/50 JP8/Gevo ATJ8, and 50/50 JP5/Gevo ATJ5 at 30°C.

The results in Table 6 compare the isentropic bulk modulus of the ATJ blends to petroleum JP-5, JP-8 and 50/50 JP5/HEFA. The bulk modulus for the JP5/Cobalt ATJ5 blend was 8.8% lower than JP-5 as reported in the CRC handbook and 1.6% lower than the 50/50 JP5/HEFA blend. Additionally, the bulk modulus for the JP5/Gevo ATJ5 blend was 10.8% lower than JP-5 as reported in the CRC handbook and 3.4% lower than the 50/50 JP5/HEFA blend. The bulk modulus for the JP8/Gevo ATJ8 was lower than petroleum JP-8 and all the other alternative fuel blends listed in Table 6. The difference in bulk modulus between the JP5/ATJ5 and JP8/ATJ8 blends can be explained by the difference in density between JP-8 and JP-5. JP-8 is less dense than JP-5 which therefore makes JP-8 easier to compress under pressure. U.S. Navy aircraft frequently operate on fuels with a lower density than JP-5, such as JP-8 or Jet A fuels without any operational impact. The bulk modulus for the JP5/ATJ5 blends were very similar to JP5/HEFA blends. Extensive aviation flight testing and qualification of HEFA blends with similar bulk modulus values have shown no adverse effects[5, 6, 7, 8, 9].

4.0 CONCLUSIONS

Two distinct batches of ATJ-5 derived from an alcohol feedstock were blended 50/50 with petroleum JP-5 and examined against MIL-DTL-5624 specifications, Fit-For Purpose Level I and Level II acceptance criteria. The 50/50 blends of JP5/ATJ5 showed chemical and physical properties that were as good as or better than petroleum JP-5. Both 50/50 JP5/ATJ5 blends met all MIL-DTL-5624 specifications criteria, with the exception of residue content for the JP5/Gevo ATJ5 blend. Distillation residue will meet spec requirements for bulk procurements of ATJ. The 50/50 JP5/ATJ5 blends also met all FFP Level I and tested Level II criteria except viscosity at -40°C for both blends and cetane number for the GEVO ATJ-5 blend. Viscosity at -20°C of the blends met the JP-5 specification; however fell within the top 20% of historical maximum viscosity values for petroleum JP-5 at -20°C. Additional investigation is being done to assess any potential risk of operating with viscosity in this regime.

5.0 RECOMMENDATIONS

It is recommended that 50/50 blends of petroleum JP-5 and butanol-based ATJ-5 continue aviation qualification testing. Blending ratios should be reduced to ensure the fuel meets cetane number for diesel engine qualification.

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[1] Turgeon, R.T, Morris R., Williams, S.A, Kamin, K.A, Mearns, D.F. NF&LCFT SWP 44FL-006 "Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/ Fuel Sources."

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[18] ASTM International D4054 – 09, “Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives,” 2009.

APPENDIX A
Procurement Specification for Alcohol to Jet (ATJ-5)[1]

Materials: Alcohol to Jet (ATJ-5) fuel supplied under this procurement shall consist predominately of n-paraffins, iso-paraffins, and cycloparaffins and shall be produced solely from alcohols which have been subsequently dehydrated to olefins, oligomerized and hydroprocessed into jet fuel range hydrocarbons.

Properties	ASTM Number	Min	Max
Flash Point, °C	D93	60	
Density @15°C, kg/L	D1298, D4052[h]	0.760	0.845
Total Water, ppm	D6304		75
Particulate, mg/L	D5452[h], D2276		1.0
Filtration Time, min	MIL-DTL-5624 Appendix A		15
Kinematic Viscosity @ -20°C, mm^2/s	D445		8.5
Cetane Number or Derived Cetane Number	D613[h], D6890	Report [i]	
Distillation	D86		
IBP, °C		Report	
10% (T10), °C			205
50% (T50), °C		Report	
90% (T90), °C		Report	
FBP, °C			300
Residue, vol%			1.5
Loss, vol%			1.5
T90-T10, °C		25	
Copper Strip Corrosion @ 100°C	D130		No1
Freezing Point, °C	D2386[h], D5972		-46
Hydrogen Content, mass %	D7171	13.4	
Heating Value, MJ/kg	D4809	42.8	
MSEP [j]	D3948	80	
Total Acid Number, mg KOH/g	D3242		0.015
JFTOT@ 325 °C	D3241		
Tube Deposit Rating			<3
dP, mmHg			25
Antioxidant [k], ppm		17.2	24.0
CI/LI [l]			

h. Referee test method.
i. Cetane number is not limited but it is desirable that the cetane number (or derived cetane number) be greater than 30.
j. MSEP value shall be determined on a lab hand blend of the finished fuel with all additives required by the specification (AO and CI/LI).

k. Antioxidant shall be added as soon as practicable after hydroprocessing or fractionation synthesizing and prior to the product or component being passed into storage to prevent peroxidation and gum formation after manufacture. The following antioxidant formulations are approved:

  a. 2,6-di-tert-butyl-4-methylphenol
  b. 6-tert-butyl-2,4-dimethylphenol
  c. 2,6-di-tert-butylphenol
  d. 75 percent min-2,6-di-tert-butylphenol
     25 percent max tert-butylphenols and tri-tert-butylphenols
  e. 72 percent min 6-tert-butyl-2,4-dimethylphenol
     28 percent max tert-butyl-methylphenols and tert-butyl-dimethylphenols
  f. 55 percent min 2,4-dimethyl-6-tert-butylphenol and
     15 percent min 2,6-di-tert-butyl-4-methylphenol and
     30 percent max mixed methyl and dimethyl tert-butylphenols

l. Corrosion inhibitor/lubricity improver additive. A corrosion inhibitor/lubricity improver (CI/LI) additive conforming to MIL-PRF-25017. The amount added shall be equal to or greater than the minimum effective concentration and shall not exceed the maximum allowable concentration listed in the latest revision of QPL-25017.

Detailed Process Requirements of Alcohol to Jet (ATJ-5)

	ASTM Method	Min	Max
Hydrocarbon Composition, mass % Paraffins (normal and iso), mass% Cyclo Paraffins, mass % Total Aromatics, mass %	D2425	Report	30 0.5
Sulfur Content, ppm	D5453		15
Nitrogen Content, ppm	D4629		10
Metals (Ca, Cu, Fe, Mg, Mn, Ni, P, Pb, V, Zn,), ppm	D7111		0.5 total
Alkali Metals and Metalloids (B, Na, K, Si, Li), ppm	D7111		1.0 total

Appendix A References:

[1] ASTM International D7566– 14, “Specification for Aviation Turbine Fuels Containing Synthesized Hydrocarbons,” Approved 2009, Updated Reapproved 2014. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428

APPENDIX B
Fit for Purpose Level I Requirements

Property	Test Method	Units	Acceptance Criteria Min	Acceptance Criteria Max	Primary Property Performance Driver	Relevant SME/TWH
FFP - Level I Properties						
Chemistry and Composition Properties						
Hydrocarbon Composition Analysis	ASTM D2425 or In-House Method (Appendix A-3)[m]	Vol %	Conform		Bulk fuel physical properties deviations	AIR: Fuels Systems
Aromatics	ASTM D1319 or	Vol %	8	25	Low: Elastomer sealing, bulk fluid density	AIR: Fuel Systems, Combustors,
	ASTM D6379	Vol %	8.4	26.5	High: Smoke and deposit formation	Materials, Engine Controls
Naphthalenes	ASTM D1840	wt%	---	3.0	High: Smoke and deposit formation	AIR: Fuel Systems, Materials, Engine Controls
Carbonyls	ASTM E411	mg/kg (ppm)	Conform		High: Thermal stability, fuel nozzle fouling	AIR: Fuel Systems
Alcohols	EPA Method 8015	mg/L	Conform			
Esters	EPA Method 8260	mg/L	Conform			
Phenols	EPA Method 8270	mg/L	Conform			
Nitrogen Content	ASTM D4629	mg/kg	Conform		High: Storage stability, soot formation	AIR: Fuel Quality, Fuel Systems
Trace Copper	ASTM D6732	μg/kg (ppb)	---	20	High: Thermal stability, fuel nozzle fouling	AIR: Fuels Systems, Combustors
Trace Metals & Elements Ag, Al, B, Ba, Ca, Cd, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Si, Sn, Ti, V, Zn	ASTM D7111 or UOP 389	mg/kg	Conform		High: Propulsion hot section corrosion, fuel nozzle fouling	AIR: Fuels Systems, Combustors
Existent Hydroperoxides	ASTM D3703	ppm	---	8	High: Storage stability, elastomer damage	AIR: Fuel Quality, Fuel Systems
Bulk Physical and Performance Properties						
Fuel & Additive Compatibility	ASTM D4054, Annex A2	-----	Conform		Fuel and additive blending compatibility	AIR: Fuel Systems
Lube Oil Compatability	In-House Method, (Appendix A-4)[m]	-----	Conform		Fuel and lube oil blending compatibility	NAVSEA
Density vs. Temperature	ASTM D4052	kg/L vs. °C	Conform, see Figure A-1-1 for Typical values[m]		Thermal expansion of fuel, fuel flow calculations, metering device accuracy, fuel loading	AIR: Fuel Systems, Engine Control Systems
Distillation Curve	ASTM D86	°C vs. vol%	Conform, see Figure A-1-2 for Typical Values[m]		Volatility, ignition, fuel boiloff	AIR: Fuel Systems, Engine Control Systems
Distillation T50 - T10	ASTM D86	°C	15	---		
Distillation T90 - T10	ASTM D86	°C	40	---		
Simulated Distillation	ASTM D2887	°C vs. vol%	Conform			
Viscosity vs. Temperature	ASTM D445	cSt vs. °C	Conform, see Figure A-1-3 for Typical Values[m]		High: Atomization, spray pattern, pumpability, water coalescence	AIR: Fuel Systems, Combustors, Engine Controls
Interfacial Tension	ASTM D971	dynes/cm	20	---	Low: Atomization, injector spray pattern, pumpability	AIR: Fuel Systems, Combustors, Engine Controls
Volumetric Heating Value	ASTM D4809	MJ/L	33.5	---	Low: Engine power, vehicle range	AIR: Combustors, Fuel Controls
Pour Point	ASTM D97	°C	---	-56	High: Low-temp pumpability and transport	AIR: Fuel Systems
Thermal Oxidative Breakpoint	ASTM D3241	°C	Conform		Low: Fuel nozzle fouling, deposit formation	AIR: Fuel Systems, Combustors
Lubricity, BOCLE Wear Scar	ASTM D5001	mm	---	0.65	High: Component scuffing,wear and stiction	AIR: Fuel Systems, Engine Control Systems
Lubricity, HFRR Wear Scar	ASTM D6079	μm	Conform		High: Component scuffing,wear and stiction	NAVSEA
Response to Corrosion Inhibitor / Lubricity Improver Additive	In-House Method (Appendix A-5)[m]	mm vs. mg/L	Conform, see Figure A-1-4 for Typical Response[m]		Component scuffing,wear and stiction	AIR: Fuel Systems, Engine Control Systems
Response to Static Dissipator Additive	In-House Method (Appendix A-6)[m]	pS/m vs. mg/L	Conform		Conductivity, static charge dissipation	AIR: Fuel Systems, Infrastructure
Autoignition Temperature	ASTM E659	°C	226.7	---	Low: Shipboard fire safety	AIR: Engine Control Systems SEA: Fire Safety
Cetane Number, Derived	ASTM D6890	-----	42	---	Low: Diesel engine starting, smoke formation, engine wear	NAVSEA
Storage Stability (Antioxidant)	In-House Method (Appendix A-7)[m]	Δ mg/kg	Conform		High: Storage stability, elastomer damage	AIR: Fuel Quality, Fuel Systems
Storage Stability (Gums)		mg/100mL	---	7		
Storage Stability (Peroxides)		mg/kg	---	16		
Water Solubility @ 30 °C	In-House Method (Appendix A-8)[m]	mg/kg	Conform		Low: Fuel system component corrosion, microbial growth	AIR: Fuel Systems, Engine Control Systems, Fuel Quality

[m] Test methods are outlined in corresponding appendices in the NF&L CFT SWP 44FL-006 “Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/Fuel Sources.”

Conformance indicates that the test fuel has a similar response to that of conventional fuels, falls within the range of experience measured for conventional fuels, demonstrates similar or improved characteristics when compared to typical JP-5 fuel, or falls within the bounds of Fit-for-Purpose acceptance criteria.

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APPENDIX C
Fit for Purpose Level II Requirements

FFP - Level II Properties

Property	Test Method	Units	Acceptance Criteria Min	Acceptance Criteria Max	Primary Property Performance Driver	Relevant SME/TWH
Bulk Modulus, Tangent vs. System Pressure @ 30°C and 60 °C	ASTM D6793	MPa vs. MPa	Conform, see Figure A-2-1 for Typical Values[n]		Low: Fuel injection timing, atomized spray pattern	AIR: Fuel Systems, Engine Control Systems, Combustors
Dielectric Constant vs. Density	ASTM D924	Const. vs. kg/L	Conform, see Figure A-2-2 for Typical Values[n]		Dielectric constant compensated gauging systems	AIR: Fuel Systems, Engine Control Systems
Gas Solubility, Ostwald Coefficient	ASTM D2779	-----	Conform, see Figure A-2-3 for Typical Values[n]		High: Fuel system pressure decrease, fuel pump cavitation	AIR: Fuel Systems, Engine Control Systems
Thermal Conductivity vs. Temperature	ASTM D2717	W/m*K vs. °C	Conform, see Figure A-2-4 for Typical Values[n]		Low: Insufficient heat transfer to and from fuel, heat exchanger design	AIR: Fuel Systems, Engine Control Systems
Specific Heat vs. Temperature	ASTM D2766	kJ/kg·K vs. °C	Conform, see Figure A-2-5 for Typical Values[n]		Low: Insufficient heat transfer to and from fuel, heat exchanger design	AIR: Fuel Systems, Engine Control Systems
Surface Tension vs. Temperature	ASTM D1331	mN/m vs. °C	Conform, see Figure A-2-6 for Typical Values[n]		Low: Fuel atomization, spray pattern	AIR: Fuel Systems, Engine Control Systems, Combustors
Vapor Pressure vs. Temperature	ASTM D6378	psia vs. °C	Conform, see Figure A-2-7 for Typical Values[n]		High: Vapor lock, hard starting, venting loss	AIR: Fuel Systems, Engine Control Systems
Vapor/Liquid Ratio	SAE ARP492C	Vol% (vap.) / Vol% (liq.)	Conform			
Diesel Combustion, Ignition Delay	In-House Method (Appendix A-9)[n]	ms (Alt fuel) / ms (JP-5)	0.80	1.20	Diesel engine starting and combustion efficiency	NAVSEA
Diesel Combustion, Max Rate of Heat Release		J/s (Alt fuel) / J/s (JP-5)	0.85	1.15		
Diesel Combustion, Location of Peak Pressure		Degrees After Top Center	4	18		
Fire Safety Test	In-House Method (Appendix A-10)[n]	-----	Conform		Extinguishing agent performance and firefighting capability	NAVSEA
Flammability Limits @ 100ºC	ASTM E681	Vol%	Conform		Self-sustained combustion, altitude relight	AIR: Fuel Systems, Engine Control Systems, Combustors
Hot Surface Ignition Temperature	FED-STD-791, Method 6053 or ISO 20823	ºC	Conform		Low: Shipboard fire safety	AIR: Engine Control Systems SEA: Fire Safety
Microbial Growth, Potential	In-House Method (Appendix A-11)[n]	-----	Conform		High: Filter/coalescer blockage, tank corrosion	AIR: Fuel Systems Infrastructure
Navy Coalescence Test	In-House Method (Appendix A-12)[n]	-----	Conform		Water separability	AIR: Fuel Systems Infrastructure
Oil Pollution Abatement	In-House Method (Appendix A-13)[n]	-----	Conform		Oil / water separation, ability to meet environmental discharge regulations	NAVSEA
Response to FSII Additive	In-House Method (Appendix A-14)[n]	-----	Conform		Low temperature operability and performance	AIR: Fuel Systems, Engine Control Systems
Toxicity	In-House Method (Appendix A-15)[n]	-----	Conform		Personnel Safety	General
Copper Migration	In-House Method (Appendix A-16)[n]		Conform		Fuel stability, deposit formation	AIR: Fuel Systems, Engine Control Systems
Materials Compatibility, Gas Turbine Hot Section	ASTM D4054	-----	Conform		Compatibility with gas turbine hot section coatings and materials	AIR: Materials
Materials Compatibility, Metallics	In-House Method (Appendix A-17)[n]	-----	Conform		Compatibility with fuel-wetted metallic materials	
Materials Compatibility, Non-Metallics		-----	Conform		Compatibility with fuel-wetted non-metallic materials	

[n] Test methods are outlined in corresponding appendices in the NF&L CFT SWP 44FL-006 "Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5, Qualification Protocol for Alternative Fuel/Fuel Sources."

Conformance indicates that the test fuel has a similar response to that of conventional fuels, falls within the range of experience measured for conventional fuels, demonstrates similar or improved characteristics when compared to typical JP-5 fuel, or falls within the bounds of Fit-for-Purpose acceptance criteria.

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14. ABSTRACT
This test report summarizes specification and fit-for-purpose (FFP) test results of a 50/50 blend of petroleum JP-5 and two alternative fuel blend stocks produced via the alcohol-to-jet synthetic paraffinic kerosene (ATJ-SPK) process (herein referred to as 50/50 JP5/ATJ5). ATJ-SPK was made by converting a biomass to an alcohol intermediary to a hydrocarbon that meets military specification. The end product of the ATJ SPK process is very similar in chemistry to previously qualified aviation alternative fuel blend stocks, such as Hydroprocessed Esters and Fatty Acids (HEFA) and Fischer Tropsch (FT).
Two distinct batches of ATJ fuels were evaluated. These two batches were produced from two different types of butanol intermediaries, but showed overall similar chemistry and physical properties. One of the 50/50 JP5/ATJ5 blends passed all FFP requirements set forth by in the Navy Standard Work practice 44FL-006 (Naval Fuels and Lubricants CFT Shipboard Aviation Fuel, JP-5). The second 50/50 JP5/ATJ5 blend had a derived cetane number outside the range of petroleum JP-5. Cetane only affects diesel engines and mitigations for low cetane fuels in diesel engine applications are being considered. Viscosity at -20°C of the blends met the JP-5 specification; however these values fall near the upper end of the normal range operating experience. Additional investigation is being done to assess any potential risk of operating with viscosity in this regime. When both ATJ fuels are blended with petroleum JP-5, the properties of the two blends are very similar to one another. These test results support the continued qualification of 50/50 JP5/ATJ5 for use by the U.S. Navy and provide documentation to support the approval of all butanol based-ATJ blends under one qualification process.

15. SUBJECT TERMS
JP-5, ATJ-5, Alcohol to Jet Fuel, Alternate Fuel Sources

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